AN ANALYTICAL DECISION APPROACH TO RURAL TELECOMMUNICATION INFRASTRUCTURE SELECTION

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LIST OF ABBREVIATIONS

AHP……..……... Analytic Hierarchy Process
ANP………...…… Analytic Network Process
BOCR………...… Benefits, Opportunities, Costs and Risks
DM………...…….. Decision Maker
ELECTRE…...…... Elimination and Choice Translating Reality
GDSS……...…….. Group Decision Support system
HIPRE 3+…..…… HIerarchical PREference analysis
MADM…..……… Multi Attribute Decision Making
MAUT……..……. Multi Attribute Utility Theory
MAVT……..……. Multi Attribute Value Theory
MCDA………...… Multi Criteria Decision Analysis
MCDM………..… Multiple Criteria Decision Making
MODM……....… Multi Objective Decision Making
NNP…...………... Neural Network Process
OR/MS………..… Operation Research/Management Science
PROMETHEE...… Preference Ranking Organisation Method for Enrichment Evaluations
SMART……..…... Simplified Multi-Attribute Rating Technique
SMARTER…..….. a modified Simple Multi-Attribute Rating Technique
SMARTS……...…... SMART using Swings
SODA……...……. Strategic Options Development and Analysis
SSM…………...… Soft Systems Methodology
SWING……..…... Simple multi-attribute weighting method based on ratio estimation
Web-HIPRE…...… Web-HIPRE (HIerarchical PREference analysis on the Web)
WINPRE…...……. Workbench for Interactive Preference Programming

ABSTRACT

Telecommunications infrastructure is recognised as the fundamental factor for economic and social development for it is the platform of communication and transaction within and beyond geographical boundaries. It is a necessity for social benefits, growth, connection and competition, more in the rural communities in developing countries. Its acquisition entails great investment, considering the emergence of various technologies and thereby making the selection a critical task.

The research described in this thesis is concerned with a comprehensive examination and analytical procedures on the selection of technologies, for rural telecommunications infrastructure. A structured systematic approach is deemed necessary to reduce the time and effort in the decision-making process.

A literature review was carried out to explore the knowledge in the areas of Multi-Criteria Decision-Making (MCDM) approaches, with particular focus on the analytical decision processes. The findings indicate that, the Analytic Hierarchy Process (AHP) / Analytic Network Process (ANP) are powerful decision methods capable of modelling such a complex problem.

Primarily, an AHP model is formulated, however, since the problem at hand involves many interactions and dependencies, a more holistic method is required to overcome its shortcomings by allowing for dependencies and feedback within the structure. Hence, the ANP is adopted and its network is established to represent the problem, making way to telecommunications experts to provide their judgements on the elements within the structure. The data collected are used to estimate the relative influence from which the overall synthesise is derived, forming a general ANP model for such a rural telecommunications selection problem.

To provide a more wide-ranging investigation regarding selecting a potential rural telecommunications infrastructure, another systematic analysis that utilises a BOCR-based (Benefits, Opportunities, Costs and Risks) ANP was conducted. The obtained results indicate that Microwave technology is the most preferred alternative within the context of the developing countries. Sensitivity analysis was performed to show robustness of the obtained results. This framework provides the structure and the flexibility required for such decisions. It enables decision makers to examine the strengths and weaknesses of the problem, by comparing several technology options, with respect to appropriate gauge for judgement. Moreover, using the ANP, the criteria for such a technology selection task were clearly identified and the problem was structured systematically.

A case study was carried out in Libya involving its main telecommunications infrastructure provider to demonstrate how such rural technology selection decisions can be made within a specific developing country's rural area. Based on the results of this case study that were in agreement with the focus group's expectations, it can be concluded that the application of the ANP in the selection of telecommunications technology, is indeed beneficial. In addition, it is believed that telecommunications planners could, by the use of data pertaining to another rural area, utilise the developed model to propose appropriate solutions. If new criteria and/or alternatives emerge to satisfy changing business needs, they can also be included in the ANP model.

DECLARATION

The research work reported in this thesis was carried out in the School of Mechanical, Aerospace and Civil Engineering, University of Manchester, UK, from 2007 to 2010, under the supervision of Dr Margaret Emsley and Dr Ludmil Mikhailov.

This study represent original work by the author and that no portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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RESEARCH PAPERS BASED ON THIS STUDY

1. Gasiea, Y., Emsley, M., and Mikhailov, L. (2009). "*An ANP approach to rural telecommunications infrastructure selection"* 2nd Academic Symposium of Libyan Students studying in UK universities*,* Richmond Building, University of Bradford, Bradford, West Yorkshire, UK *(June, 2009). Accepted & Presented*
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1. INTRODUCTION

1.1 Background to the problem

In more than 150 years, this world has seen communications technologies leap from electric telegraph to modern mobile communication technology and its integration with computer technology. This rapid technological change was driven by the demands of information access. Considering information as power, access to it is key to many development activities, including agriculture, industry, education, health and social services (Hudson, 1999). It is for this purpose that telecommunications technology became a tool for the delivery of information, affecting all sectors from business to education, from healthcare to entertainment. Telecommunications is a key element in any country's strategy for reconstruction and development as it offers information links between urban and rural areas that can overcome distance barriers which obstruct development. In urban areas there is dynamic competition for long distance, wireless telephone, and broadband internet access. However, in rural areas, even basic telephone services may become difficult or impossible to maintain for many of their inhabitants. Such areas are technologically poor and need special consideration and efforts if they are to actively participate in the information age. Considering its inhabitants, it is of great matter that a large portion of the global population lives there; seven out of ten poor people in the world live in rural areas, 85% of the population of least developed countries and 75% of Asian people in developing countries are living in rural areas (World Bank, 2005).

Developments in telecommunications technologies make it possible to supply services in rural areas at prices, which were earlier not possible. The potential of telecommunication services to help rural areas overcome some of their historic disadvantages is tremendous. Rural communities need better services to compensate for their geographical isolation and cost of being far from the cities. By making the distance immaterial, telecommunications can provide rural areas with services comparable to those found only in urban areas. However, many obstacles stand in the way. Inherent characteristics of rural areas (remoteness accompanied by inaccessible terrain, low population density, scattered settlements, etc.) mean that they stand a real chance of missing out on the telecommunications revolution. Consequently, access to telecommunication services and its efficient deployment is crucial, which justifies the fact that despite that people in rural and remote areas do not have these facilities, it does not mean they do not need them.

In view of the fact that rural areas are developing, even though with varying needs, telecommunication infrastructures and services provision also need to develop. However, the provision of such services is a complex process that involves both technical and socio-economic factors. It also involves a combination of different network elements, processing and business services. Therefore, it is considered a demanding activity considering the inadequate infrastructure and scattered settlements, characterised by sparse populations.

The planning and development of telecommunications infrastructure projects in such a relatively dynamic and risky environment require longer time involving a substantial number of manpower from many suppliers than in urban centres. Project management techniques are therefore needed to prevent the fragmentation that may plague such projects. The increased interest in project management techniques in telecommunication services can be attributed to several factors such as changes in regulations, which have imposed the unbundling of many services into their individual constituents and the increased number of new technologies that have became available to service providers. This combination of regulatory and technological changes has increased the number of potential suppliers and candidate solutions. The diversity of choices at each level of the service hierarchy that includes infrastructure, network, application and content made the interactions among vendors, sponsors and customers extremely complex. The present architecture of telecommunication services can be sketched in a network structure as shown in Figure 1.1 (Adapted and revised from Sherif, 2006).

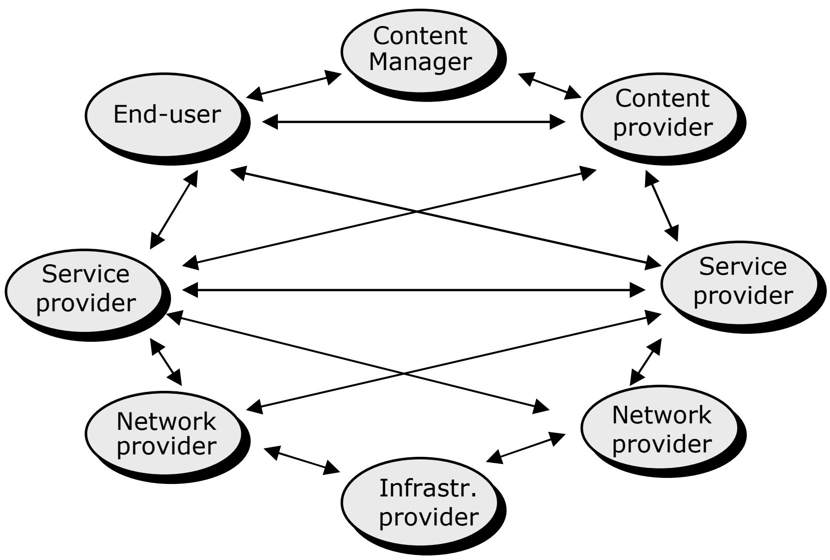

Figure 1.1 The current architecture of telecommunication services

An infrastructure provider is responsible for making transmission bandwidth available. These include: Fibre cables, undersea cables, satellite, etc. A network provider can then build, operate and maintain the network elements and infrastructure. The service provider buys network services from a network provider and then resells them to end-users, other service providers, and content providers, which can be an internet service provider (ISP), a provider of disaster recovery or a storage area network (SAN) provider, a call centre operator, a web host, etc. The content provider is responsible for content creation and can consolidate catalogues (e.g. directory services), store voice messages, provide answering services (call centres), or provide digital certificates. Finally, the content manager is responsible for managing customer relationships, packaging contents from several content providers, facilitating electronic payments, acting an exchange or a market place for electronic commerce, storing content, and so on. The above architecture clearly shows that many independent entities have to cooperate to integrate their particular subcomponent in an end-to end service offer.

Several International Telecommunications Union (ITU) studies, (ITU, 1989; ITU-D, 1997 and ITU-D7, 1998) identified the need to investigate various issues related to the deployment of telecommunication services to settlements of rural communities as a problem requiring urgent action. These studies have also shown that telecommunications, particularly in rural areas, can facilitate many development activities, such as agriculture, industry, education, health care, etc. and that a substantial expansion of its infrastructure would be a powerful driver for meeting the ICT goals for development. Furthermore, without adequate connections to telecommunications infrastructure and services, rural communities may not be able to participate in the emerging information economy. Also, the provision of telecommunication services to sparsely populated areas is usually more expensive than to densely populated areas. Inhabitants inherently experience poor access to medical facilities, high unemployment, relatively low incomes and uncomfortable schools, among other things. For these and other reasons, it is common to note a steady decline in population in rural areas. To avoid further decline, some measures must be taken to ensure that they have feasible access to telecommunication services.

The greatest challenge therefore for developing countries is to ensure that relevant telecommunications infrastructure and services are extended effectively and efficiently throughout rural areas. The enhancement of telecommunications access through the expansion of the connectivity to rural and remote areas will facilitate the rollout of the appropriate telecommunication services. However, one has to examine the means to address the critical challenge of providing such connectivity and to deal with uncertainty and multiple conflicting objectives. “Connectivity is a central enabling agent in building the Information Society. Universal, ubiquitous, equitable and affordable access to ICT infrastructure and services constitutes one of the challenges of the Information Society and should be an objective of all stakeholders involved in building it” (ITU, 2001).

With different criteria for technology evaluation and various alternatives available nowadays, the selection process becomes complicated. In the past, telecommunications planners have had a choice of only a few technologies to provide network access solutions, so the selection was relatively insignificant. However, nowadays, this relaxed situation is rapidly changed as a result of the ever increasing availability of technologies. There are numerous choices of modern technologies available in the market to be applied to rural and remote areas, depending on the surrounding conditions of the concerned areas. There are also different, innovative and unique technological solutions being offered all around the world by major telecommunication firms, small local operators, cooperatives and individuals to provide rural telecommunication services. However, the selection and deployment of such rural technologies are characterised by a multitude of complex issues that are not only technological but are complex due to the complexity of interactions between the various factors affecting the process (Andrew and Petkov, 2003). Accordingly, one has to consider other various issues relevant to rural areas such as sociological, demographical, environmental, political, cultural, economic and technical aspects to adequately address the selection and deployment of rural telecommunication infrastructure technologies. Also, the recently emerged telecommunication services, especially e-services, increase the number of factors by which a modern telecommunication infrastructure technology should be assessed. This will make the trend to use multicriteria decision making techniques become more common in the future.

1.2 The research problem

This research is about telecommunications infrastructure in rural areas of developing countries. As it is a fundamental factor in promoting modern services in such areas, the non-existence of such proper infrastructure will hinder or delay the delivery of such services. For most developing countries, lack of adequate telecommunications infrastructure remains a major obstacle for the promotion of affordable services in rural areas. There is a need therefore to provide access to the main telecommunications network and expand connectivity to rural areas, which will enable the rollout of the appropriate telecommunication services. However, one has to tackle key issues such as the challenge in the choice of appropriate telecommunications infrastructure technology that will provide the required e-services within various constraints.

Extensive publications of the International Telecommunications Union (ITU), which is, inter alia, responsible for setting standards and making recommendations in the telecommunications industry with respect to equipment, general policy, and planning methodologies have been reviewed by the author to examine the means to address the critical challenge of providing connectivity to rural and remote communities. Typically, technology selection is evaluated based on a mixture of different criteria, one of which is the remoteness of a village. If the village is within 35 km of the nearest local exchange, telecommunication services can be provided to that village using one-hop last-mile link. However, if the village is further away, i.e. more than 35 km from the local exchange, at least two transmission hops must be established (Pipattanasomporn, 2004). Two types of telecommunications infrastructure technologies are therefore needed to provide rural telecommunication services, namely Backbone network (Core) and Access network (Last mile). Any decision made for each of these two segments must take into account the characteristics of rural settlements.

The backbone network provides the long-haul signal transmission from the country's main telecommunication centre to the remote access network, i.e. trunking services. It is that part of the telecommunication network that never reaches the final customer directly, but is used to link together local access networks that offer a range of services, and to aggregate demand and carry it efficiently over long-distances. Backbone has national and international components. The former is considered here. This network may be wireless or wireline, and it can be based on different transmission media, e.g. Fibre optic, wireless or satellite. The access network provides the connectivity between the end-user and the backbone network. This network may be based on wireless or wire line technologies, e.g. copper wires or wireless, and is connected to network nodes at the edge of the backbone (core) network. Technologies in both networks can be circuit-switched or packet-switched (Gasiea et al. 2009a). The primary focus of this research is mainly on the backbone network by attempting to model the decision making process with regard to the selection of the most suitable backbone infrastructure technology, using appropriate MCDM methods.

The telecommunications backbone is, in general, a key problem for rural information infrastructure, as low population density is linked to high cost of service for any communications technology, especially for wireline services. It poses the greatest challenge to bringing affordable telecommunication services to rural residents. However, once it is in place and running, it will be possible to connect other nearby rural villages with a wide range of telecommunication technologies and needed services. It is in fact an essential promoter to telecommunications services in rural areas.

The correct choice of rural telecommunications infrastructure technologies, with their associated capabilities and costs, is critical to the deployment of e-services applications in rural areas of developing countries. This creates a need for a systematic methodology that can help telecommunication infrastructure providers to understand better how to reach successful investing decisions in different rural technologies. This is due to the wide variety of available technology alternatives available nowadays to the telecommunications planners/decision makers, technological differences, limited budgets, unaffordability to experiment and the multi criteria nature of the selection process. Furthermore, the need to account for economic, technical, environmental, social and regulatory factors further complicates the process of reaching the right decision with confidence and makes the rural telecommunications evaluation projects field well suited to multi-criteria decision-making.

To take the most effective action, decision makers, rural telecommunication infrastructure providers and vendors alike, have to deal with great uncertainty and complexity throughout the selection process. They need to know several things such as, who are the people who will be affected, and what are their concerns, how to include the many perspectives on a given problem and so on. Thus, one of the questions that this study attempts to raise is 'How best can telecommunications infrastructure providers select the most appropriate backbone infrastructure technology, capable of deploying e-services applications in rural areas?' and subsequently calls for the need for a more quantitative methodology and some kind of structure or model that can help telecommunications planners to understand the rural surroundings and subsequently to reach better decisions in the selection of rural telecommunications infrastructure technologies.

The nature of such a rural technology selection problem which is characterised by complexity typically involves the consideration of a set of diversified criteria such as technical, economic, social, environmental and regulatory factors which can only be modelled as a network because most other MCDM solution methods fall short in analysis (Gasiea et al. 2010). Taking these factors into consideration, the problem of selecting the most appropriate rural telecommunications infrastructure technology is to be addressed in this study by using a multicriteria approach, with particular focus on the ANP. Also, by investigating the feasibility of applying a multicriteria approach in such a rural technology selection process in a particular context, it is anticipated that relevant various issues are to be addressed, which might eventually lead to improving the group decision making process so the approach becomes more systematic and logical.

1.3 Importance of the research

This study is intended to fulfil an identified information need and offer practical help in a complex rural environment. The contribution is a comprehensive analytical decision investigation concerning the selection of telecommunication infrastructure in rural areas of developing countries. This research has implications for several sectors, such as telecommunications, government and society, some of which are:

- This research addresses the need for a strategic decision-making tool to assist management. It is, therefore, intended to be of use by policy makers in determining which telecommunications technology solution is more appropriate and most beneficial in providing and/or extending rural access to telecommunication services;
- The research is important to the telecommunication infrastructures and services providers, which will become aware of the importance of proper choice of rural technologies capable of fulfilling community's needs and wants. It is also expected that such a research approach will also be of interest to academics and practitioners of rural telecommunications, and other related subject areas;
- The research is also vital to government and society, since the decision model will not only assist in realising government imperatives regarding rural telecommunications but will provide an analytical decision model that can generate knowledge informing future policies; and
- Finally, proper provision of rural telecommunication services will result in a more efficient service being provided to rural communities. This has an impact on the wellbeing of communities that seek to use telecommunications to improve their quality of life.

1.4 Aim and objectives of the research

The main aim of the research is to provide a comprehensive examination regarding rural telecommunications infrastructure selection by conducting an analytical decision analysis within the context of developing countries. The Multi Criteria Decision Making (MCDM) approach, specifically, the analytic network process, will play the key guiding role in the process. The case study will involve Libya's main telecommunications provider in terms of modelling such a selection process for a potential rural area.

It should be noted that this research is not intended to suggest any improvements or modifications to the analytic network process method, but rather to show how this can be used to solve a real life problem, complex and multicriteria in nature, which is exemplified through the case study. By doing this, it is intended to develop a structure, which could, albeit with some modifications to suit the prevailing circumstances, be used to solve other problems of a similar nature.

The main aim will be pursued through the following objectives:

1. To examine and analyse the issues and challenges involved in the selection of rural telecommunications technologies in developing countries;
2. To explore and analyse suitable Multi Criteria Decision Making (MCDM) methods, namely, the Analytic Hierarchy Process (AHP) / Analytic Network Process (ANP) that can be applied to select the most appropriate rural telecommunications technologies;
3. To formulate generic AHP/ANP decision models for selecting potential technology options concerning rural telecommunications infrastructure;
4. To develop a comprehensive BOCR-based (Benefits, Opportunities, Costs and Risks) ANP framework that will enlighten such a selection process in developing countries;
5. To validate the generic ANP model in a real case study in Libya, to evaluate its applicability in terms of systematically improving the group decision making process of the selection process; and
6. To draw conclusions for improvement of decision processes related to rural telecommunications infrastructure selection.

1.5 Motivations, scope and limitations of the research

The motivations behind tackling this research work is based mainly on the author's own personal interest in the subject matter and to find ways to facilitate access to new telecommunication services to those who are underserved: inhabitants of rural areas.

The scope of this research is to analytically examine the selection of telecommunication technology to promote rural infrastructure development in a particular context. However, this research is not about rural development in itself, as this would require a separate study on its own to deeply investigate the link between the deployment of rural telecommunications and rural development. The role of telecommunication in rural development will be briefly introduced in subsection 2.3.1.

Even though using a developing country as a model, still the main focus should be on developing a general model which could be applied within a defined scope, taking into account that "case studies are generalizable to theoretical propositions and not to populations or universes, i.e. the main goal will be to expand and generalize theories (analytic generalization) and not to enumerate frequencies" (Yin, 2003). The analysis of such a particular case or situation ought to be used as a basis for drawing conclusions in similar situations. Thus, it is assumed that the conducted investigation can be modified to suit the unique needs of other rural areas, particularly in developing countries with similar characteristics to the said country.

Given the time and financial constraint of such a study, it will not be possible to engage in a comprehensive practical implementation of the proposed model's outcome. Rather the overall aim will be to validate the model through a case study.

1.6 Outline of the research methodology

The research area of concern in this study is the selection of rural telecommunications infrastructure technology for the benefit of all related stakeholders. Examination of previous research on rural telecommunications was necessary in deciding the scope of the study. Hence, from the early stages of this work, initial information was gathered and investigations of the problem situation were conducted. Two activities were used as means to generate the necessary information. These include interactions with many scholars interested in rural telecommunications and intensive literature survey. The latter was conducted on the following aspects:

- The current planning approaches of rural telecommunication infrastructure;
- The various issues, factors and players involved in the choice of rural telecommunication technologies; and
- The current status of MCDM field, in particular the AHP/ANP methods and their potential applicability to model the technology selection process.

Furthermore, the deployment of rural telecommunication services and infrastructures in developing countries is considered by many researchers as a complex system of people and technology (see, Andrew and Petkov, 2003 and Nepal, 2005) interdependent on other systems/subsystems and characterised by multiple stakeholders. Hence, the issues involved in the choice of technologies to deploy such services, if all concerned stakeholders are to benefit, are often complex, cutting across various aspects of rural society. This issue triggered the need to consider the selection process from multiple perspectives, explore methodologies that will facilitate participation and engagement, and include improvement of the difficulties experienced by the deprived rural communities. Therefore, it was anticipated that a systems thinking approach would yield far more value than is possible from other approaches, as it addresses such complexities. For the above reasons, the author initially spent a considerable period of time exploring various possibilities of applying the systems thinking approach to tackle such a problem. This process comprised of different activities, for example, collecting published literature, reading broadly about the subject, locating, contacting and discussing the research problem with several academics involved in such a field. However, the author eventually abandoned the idea of using such a method because of numerous emerged obstacles.

The review of the existing literature on rural telecommunications also indicated the applicability of a MCDM modelling approach. It was therefore decided that this approach would be used as the dominant research methodology. In particular, the AHP/ANP methods will be applied in the context of executive decisions that include qualitative attributes, in relation to conflicting objectives, in reaching a compromise decision in a typical rural telecommunications situation. This will lead to the development, primarily, of a decision model to highlight and select the most appropriate infrastructure technology. A detailed description of the abovementioned methods is presented in chapter 4.

In order to identify the selection criteria, assess their importance and identify dependencies among these criteria, two online survey questionnaires have been conducted as explained later. Pairwise comparisons data were also collected through several online surveys that were designed and addressed to telecoms experts. The rural telecommunications technology alternatives are initially evaluated with the generic AHP model developed to model the selection process. To overcome the shortcomings inherited in this method, a general ANP model was subsequently developed to allow for dependencies and interactions among factors. To help telecoms decision makers decide on the most appropriate telecoms backbone alternative for rural areas and reach proper decisions in this regard, a wide-ranging BOCR-based ANP framework with the inclusion of stakeholders clusters was developed.

Finally, in order to test the generic ANP model in a real firm-level decisions, a field study involving Libya's main telecoms provider as a case study was carried out. The decision process was simulated using an experimental investigation in the form of a workshop involving a group of 15 personnel to enlighten them in identifying the most appropriate rural telecommunications technology. The participants encompassed representatives from the company's network engineering team. The outcome of a post workshop questionnaire indicated that the results obtained through the workshop were within the expectations.

1.7 Overview of the thesis

This thesis consists of nine chapters. A brief description of the remainder of this report is summarised below:

Chapter 2 presents an overview of rural telecommunications to explore the knowledge in this field. It deals with the issues that differentiate rural telecommunications from urban ones. In particular, the distinctive features of a typical rural area in a developing country, and the challenging issues that need to be considered in the provision of telecommunication services and infrastructures are mentioned. A particular reference is given to the role of telecommunications in rural development. Universal access to telecommunication services, which is one of the critical challenges facing many countries seeking to close the digital divide, is discussed. To accomplish objective (1) of this study, this chapter concludes by exploring the factors affecting the selection and deployment of rural telecommunications infrastructure.

Chapter 3 starts by discussing the current planning approaches to rural telecoms. It then explores past research in relation to rural telecommunications infrastructure planning. The most general and widely recognised model of decision making process proposed by Simon (1997) will be introduced. An overview of the MCDM methods and their underlying theory and classification will be given. Also, a comparison of several MCDM methods based reviewing the literature will be given. The next section highlights the AHP/ANP as potential MCDM methods to be used for this study and so realising objective (2) of this work. Models involving the application of the AHP/ANP in rural telecommunications are also presented. An account on the applicability of the SSM to the selection of rural telecommunications will be given. A conceptual model to justify the adopted multicriteria approach is eventually proposed. Finally, the chapter concludes by further elaborating the research methodology outlined in chapter 1, emphasising the research philosophy, approach, strategy and design, and methods used in this study.

Chapter 4 discusses in detail the AHP/ANP methods adopted in this study. It describes the nature of hierarchal and network approaches and their use in complex decisions. All AHP aspects such as principles and axioms, fundamental scales, paired comparisons and synthesis are discussed. Next, the ANP theory and methodology are described including structuring of the decision problem, dependency assessment, measurement and data collection, determination of normalised weights, supermatrices creation and synthesis. The chapter concludes by discussing the suitability of using the ANP as a dominant methodology in this study together with some ANP disadvantages.

Chapter 5 explains in detail several steps related to structuring the problem and constructing the model. This includes setting the technology selection criteria followed by conducting an online survey and analysing the obtained results. Grouping of the criteria and alternatives into clusters, along with their description and assessing dependencies among them is also explained.

Chapter 6 deals with the formulation and estimation of the AHP/ANP models for rural telecoms infrastructure selection, aiming to build up general models that can be used to facilitate and accelerate such selection processes. The four main AHP phases were applied. Each phase was carried out to elucidate how to develop such a model, demonstrating how it could be used to prioritise the four adopted technology alternatives. Then, the structure of the proposed ANP decision model described by its clusters and elements, and by the connections between them is then presented. Pairwise comparisons that emerged from all possible connections together with the online questionnaires that were designed to collect input data are described. The chapter ends by synthesising the results and hence, fulfilling objective (3).

Chapter 7 describe the general ANP methodology that includes benefits, opportunities, costs and risks, used to comprehensively examine the selection process and create the evaluation and selection framework so as to accomplish objective (4). From the perspective of decision makers and stakeholders, four technology options are evaluated with respect to several diversified factors. The objective is to select the alternative which is the most beneficial and offers the most opportunities while at the same time incurs the least cost and poses the lowest risk. The model was structured by creating three networks: the top-level network, the control criteria networks and the decision networks. The chapter concludes by carrying out sensitivity analysis to check the robustness of the results.

Chapter 8 commences by introducing an overview of the challenges that face Libya's sole telecommunications provider with respect to the operations and the level of the technological infrastructure. It then explains the methods of data collection, which were conducted during the field study. The current rural technology selection process applicable within the company was discussed followed by validating the generic ANP model in a real case study in a chosen Libyan rural town (Al Qatrūn). The aim is to demonstrate the application and effectiveness of the proposed model to achieve objective (5).

Chapter 9 concludes the thesis by fulfilling objective (6) with respect to summarising the work done and the results achieved. A summary of how the objectives of this research were addressed followed by an account on the expected research contribution. A reflection on the ANP method adopted in this study is presented. The chapter sums up by giving some concluding remarks and the recommendations made to discuss the implications of the findings and the future work to be carried out to extend and improve the results of this research.

2. ON THE NATURE OF RURAL TELECOMMUNICATION

2.1 Introduction

Telecommunications technology is evolving rapidly and will continue to evolve at a phenomenal rate. It is not simply a connection between people, but a link in the chain of the development process itself, especially in the remote and rural areas that are technologically poor. Such areas lack even basic telephone services that may become difficult or impossible to maintain for many of their inhabitants. They need special consideration and efforts if they are to actively participate in the information age.

The potential of telecommunication to help rural areas overcome some of their historic disadvantages is tremendous. It can overcome distance barriers, which obstruct development establishing information links between them and urban areas. By making the distance immaterial, telecommunications can therefore provide rural areas with services comparable to those found only in urban areas such as wireless telephone and broadband internet access. Recent developments in telecommunications technologies make it possible to supply services in rural areas at prices, which were earlier not possible (ITU, 2001).

This chapter delves into deep analysis of rural situation and the requirement of telecommunication to growth and development, economic and social well-being. Chosen areas of this study encompass those in developing countries. Introduction lingers on the term ‘rural’ from different perspectives and then describes the characteristics, environments and challenges of rural localities within the context of developing countries.

Succeeding sections explore on issues related to rural telecommunications, with the emphasis on its role in promoting development. Several applications for the well-being of rural communities are tackled, followed by a detailed account on the ‘universal access’; one of the key phrases that has been linked to the telecommunications policy environment in developing countries.

The universal access is further explained, with reference to reliable sources and the need of policies to guarantee benefit from this. The myths and principles of universal access (the availability of a telephone service at least within approximately one-hour walking distance) are also highlighted. The multi-dimensional nature of the challenges faced in the selection and deployment of rural telecommunications technologies is investigated.

Finally, the chapter concludes by further discussing the challenges faced in the selection and deployment of telecommunication infrastructures, and introducing several diversified factors affecting the establishment of such based infrastructures in rural areas

The next section explores certain aspects related to the meaning, characteristics, environments and challenges surrounding rural settings within the context of developing countries.

2.2 Rural areas in developing countries

There is no standard definition of what is rural and one's understanding varies considerably from country to country and localities, thereby making the concept of "rural" (as distinct from "urban") challenging to define. Scholars from different backgrounds (economists, geographers, sociologists, anthropologists, etc.) have been unsuccessful in reaching a consensus on a single definition. Different variables (physical, human, economic) have been considered, with several multi-criteria approaches, to define and stratify rural areas according to different needs and goals.

"In general terms, rural and remote escape specific definitions and are described in comparative context relative to urban areas, where rural populations are defined by their distance to a metropolitan area" (Ramirez, 2000). Rurality can also be determined by the amount of people per square mile (population density). Its populations are spatially dispersed, often increasing the cost and difficulty of providing goods and services effectively. An area with a low population density can be determined as more rural than that of high population density. In many developing countries, especially Africa, one may define a rural area in connection with the deprived nature of the populace. According to Hudson (1999), India, Indonesia, and China greatly exceed the rural density in Mongolia and Kazakhstan, whereas in Rwanda, Burundi and parts of Nigeria and Kenya, they are higher than the rest of rural sub-Saharan Africa.

To fully understand rural problems in developing countries, it is necessary to explore the demographic characteristics, benefits and challenges of rural environments. Rural and remote areas, even within the same country, exhibit different characteristics and trends. Disparities may be quite large, in terms of ecological aspects, human typologies and settlements, economic variables, past trends and future potential. A comprehensive set of such characteristics that defines rural areas are mentioned below. While some of these are applicable to any rural area, some are typical of developing countries (Haymann, 1987):

- Extreme climatic conditions combined with wide variations in such conditions ranging from the humidity of tropical rain forests to the scorching heat of the deserts; for instance, countries on the equatorial belt, experience high humidity and temperatures or extreme dryness combined with high temperatures;
- Difficult geographical conditions such as uneven, rough and rugged terrain where accessibility by any mode of transport is seriously hampered, for instance, steep mountains, deserts, swamps, and isolated islands;
- Less developed infrastructure, such as the none existence of all-weather roads, inadequate energy resources like public power supply, two-way communication facilities, and drinking water supply;
- Economy dominated by the agricultural sector. Service and the industrial sector of the economy are less developed. Natural wealth such as mineral resources or tourist attractions are often existing but hardly ever used; and
- Low education and very low and limited incomes for the local rural populations essentially reduce the quality of life compared with the living conditions in the major cities. As a result, the rural population seeks migration.

Kawasumi et al. (2008) adds that "The notion of rural and remote areas includes not only geographical aspects, but also encompasses marginalized and vulnerable groups of society such as minority groups". The most common challenges for rural areas in developing countries comprise a lack of adequate health care facilities; this is mainly due to the non-existence of specialised medical centres. Another continual challenge is the lack of advanced or content rich education, which is also due to low revenues and the inability to support larger school systems. Moreover, among the most serious problems is a lack of necessary funds and work opportunities, and as a consequence of scarcity of such cultural resources and opportunities for professional advancement, youths are likely to move to populated areas, which can provide higher education and career opportunities. The divide between rural and urban communities is increasing annually in terms of job opportunities, economy, education, health care, public service and public safety (Hudson, 1999).

To summarise, the above analysis could then be generalised into three kinds of factors that specify a 'rural environment':

- Economic and demographic factors where the local economy is based on agriculture or fishing and with a lower average per capita income than the urban areas;
- Geographic factors where the rural populations are remotely located from major urban centres and also isolated from each other by the nature of terrain; and
- Physical factors such as under-developed infrastructure, including transport and power distribution networks. Other physical factors include heavy rainfall and high groundwater level.

2.3 Rural telecommunications

In this day and age, one might argue that any ‘densely populated’ area without telecommunications infrastructure could be regarded as rural. While one may have a general but clear notion of ‘telecommunications’, adding ‘rural’ to this word calls for a definite explanation of what is meant by ‘Rural Telecommunications’, at least in the context of this research, and how it differs from any other telecommunications. The characteristics of a rural area, however it is defined, will affect the deployment of telecommunication infrastructure and services in that area.

In most countries around the world, the telecommunication industry has undergone some form of restructuring. Firstly, because it has became increasingly evident that telecommunications and economic development are very closely linked, and secondly because it is now widely realised that the old, rigid ‘government telecommunication monopoly model’ meets neither the communicating public’s needs nor the country’s national policy objectives (Barr, 1998).

Apart from the provision of some infrastructure for the provision of goods and services, the provision of proper telecommunications infrastructure remains neglected in many rural areas in developing countries. When the need to link underdeveloped rural areas with the more rapidly developing economic centres, as well as the general need to modernise the former is considered, it is obvious that this neglect has serious negative implications. Therefore, the greatest challenge for developing countries is to ensure that relevant telecommunication services and applications, such as telephone service, tele-health, tele-education, Internet, etc. and the resulting benefits of economic, social and cultural development, which these services promote, are extended effectively and efficiently throughout rural areas. “Telecommunications in rural areas should be able to offer the same services as in urban areas (telephone, data transmission, video transmission and other services), both for individuals (private subscribers) and for the community (public services, public booths, telecentres, etc)" (The ITU-D, 1997).

The ITU's most recent report reveals that rural telecommunications services in most developing countries are growing but still in need of improvement. The statistics on telephony services (fixed & mobile) and internet access indicate that (ITU, 2010):

- The worldwide number of mobile telephony subscribers is likely to reach the 5 billion mark by 2010. Mobile cellular networks already cover close to 90% of the world population;
- 50% of the world's inhabitants live in rural areas and 75% of rural population are covered by mobile cellular networks. The lowest coverage is in Africa, where just over 50% of the rural population is within reach of a mobile cellular network. Africa also recorded the biggest increase in rural mobile population coverage between 2000 and 2008;
- The majority of the population in developed countries lives in urban areas. Thus, 95% of rural areas in such countries are covered by a mobile cellular network signal. Although more than half of rural households have a mobile telephone, very few have Internet access;
- Coverage by a mobile cellular signal is expected to reach 100% by 2015, and all regions of the world will achieve full mobile coverage of rural populations, with more than half of the world's population using a mobile telephone. The one exception is Africa, but even there rural coverage could exceed 90% by 2015;
- Rural households in developing countries rely more on mobile than on fixed telephony, and while fixed telephone penetration in rural households often remains below 5%, mobile penetration rates are much higher, reaching over 50%;
- By the end of 2009, China's telephony services were available to 99.86% of the country's villages, while internet access covered 91.5%. China's fixed broadband currently accounts for half of broadband subscriptions in developing countries. By December 2008, 91% of India's villages had a telephone service;
- About 26% of the world's population were online at the end of 2009, and more than half the world's inhabitants have access to ICTs within their reach. However, over 80% of people in developing countries still do not have access to the Internet;

- In the developed countries, almost 60% of households had Internet access, compared to only 12% in the developing world. Penetration of fixed broadband Internet access was far lower, at about 3.5% at the end of 2009. Rural households with Internet access penetration levels remain extremely low, and a number of low-income countries have 0% of household Internet access. Broadband in the rural households is not available at all; and
- Some 37% of localities had a community access point. In rural localities, the figure dropped to under 5%. For the developing world as a whole, 8% of localities had Internet access. The percentage of localities with broadband access is lower.

2.3.1 The role of telecommunications in rural development

Rural areas are at a particular disadvantage because they do not receive the technology as quickly as urban areas do. Absence of telecommunication infrastructure and services prevents rural communities from benefiting from the quality of life and economic opportunities that new technologies bring. Therefore, one must recognize its potential and learn more of its capabilities, especially in rural development. The focus of this research is on the provision of rural telecommunication infrastructure, as a major part of rural development. A deeper understanding of the essential features of the latter is considered a precondition for the planning and rollout of rural telecommunication services and thus deemed necessary by the author, to emphasize the aim of this research.

Planning of rural telecommunication infrastructure should first consider the development of rural areas as an essential part of a coordinated evolution in a given country (ITU-D, 2006). The role of such infrastructures for development has been agreed to be remarkable by several authors, especially in developed countries (Hudson, 1995). Development as a concept, especially rural, has many implications. One may view it as economic progress while another may view it as the modernisation of facilities and services or industrialisation. Goulet (1985) gave his three views as follow:

1. Development as synonymous with economic growth in aggregate terms, where one measure is based on Gross National Product (GNP) per capita;
2. Development as "development = economic growth + social change"; and
3. Development viewed in terms of ethical values, which centres on the qualitative improvement in all societies and in all groups and individuals within societies.

Recognising the significance of telecommunications services in rural development, the ITU-D7 (1998) highlighted the following points:

- They are increasingly becoming a vital link between rural and urban areas, and between rural communities and the rest of the world;
- They represent a tool with which rural businesses and citizens can directly participate in national and global economies, thus providing opportunity to compete in the fast-growing service sector;
- They are fundamental to service industries as well as to rural economic diversification strategies; and
- They function as electronic highway, allowing urban-based industries and customers to access rural products and services, and markets more easily.

It is because of these wide-ranging and vital benefits that telecommunications services provision in rural areas should be at the forefront of any discussion on telecommunications development. This will require a delicate blend of appropriate technological choices, in combination with management and financing mechanisms, initiated at the governmental level, to support the creation of rural providers. With the ability of telecommunication to overcome the barrier of distance, it can facilitate the development process by ameliorating (Hudson, 2006):

- Efficiency: or the ratio of output to cost;
- Effectiveness: or the quality of products and services;
- Equity: or the distribution of development benefits throughout the society; and
- Reach: or the ability to contact new customers or clients.

Further, rural areas in developing countries, despite governments' legislations, remain far behind their urban counterpart in advanced telecommunication development. It is theoretically simple for the governments to approve development, but it is much harder to implement strategies to incite it (Hudson, 1999). Therefore, the issue of rural telecommunication development is commonly left for the local organisations to solve, with the hope that the quality of life and economic growth of their communities will improve over time.

Hudson (1984) proposed a series of hypotheses in an attempt to establish a theory on the role of telecommunications in development, which are subsequently demonstrated in her research and those of the ITU studies. These are listed below:

- Telecommunications use can facilitate social and improved quality of life;
- The effects of telecommunications use do not accrue exclusively to the users, but accrue also to the society and the economy in general;
- Telecommunications permits improved cost-benefits of rural social service delivery and more fair distribution of economic benefits for rural economic activities; and
- A certain level of organisational development and complementary infrastructure is required for socio-economic benefits of telecommunications to be realised.

The above issues raise an important question: How can these development matters be taken into consideration in the deployment of rural telecommunications infrastructure? Rural areas are being affected strongly by the shift to an information economy. There have been dramatic changes in both the technology of telecommunications and the regulatory environment under which the information economy operates (Hudson, 1999).

Technological innovation coupled with wireless and satellite technologies can extend connectivity to rural areas, while backbone fibre optic networks across continents and under oceans link the most isolated communities to the internet. Information technology, primarily telecommunications and computers, is part of the problem that requires rural communities to adapt to new communication technologies, and at the same time is part of the solution available to make successful adaptation possible. However, telecommunications and other information technology do not offer a 'magic solution' for rural economic development because the process involved is more complex than that. "the essentials of rural economic development can be classified into three categories (Parker, 1996):

- Investment in human capital, i.e. providing education and health care for the community;
- Investment in physical infrastructure such as water, power, transportation, and telecommunications; and
- The reform of social organisations, i.e. the way in which individuals collectively relate to each other, needs considered attention.

Much of the economic development in rural communities requires role models incentives, social support, and a variety of services — including financial, technical, accounting, legal, consulting, training, and marketing. It should be obvious that the deployment and development of infrastructure type technologies, whether it be transport, electrical power distribution, or piped water in a particular rural area, is intended for the development of that area and rural telecommunications should be no different. Numerous studies from around the world have explored the link between economic development and the presence of different levels of telecommunications infrastructure, most concluding a positive relationship between access to telecommunications capabilities and improvement in certain economic indicators (Parker, 1996; Hudson, 1999; Strover, 2001, Williams, 1995 and etc.).

Several other studies (Cronin et al., 1991 & 1994) had shown that technology could promote the deployment of other needed infrastructures for rural areas in a cost-effective and technically feasible manner. Telecommunications provision can stimulate development and is therefore an essential infrastructural component. However, installing telecommunications networks, equipment and computers will not magically change rural culture and bring about development. It may take strong leadership and organized social pressure to obtain the necessary infrastructure in the first place.

Nonetheless, Hudson (1984) stated "As a developmental tool, telecommunications has been largely ignored by planners and theorists. It is generally grouped with public utilities and infrastructure, ranking far below roads, power supply, water, and sanitation as investment priorities. Yet telecommunications is a tool for the conveyance of information, and it is the lack of the consideration of the role of information in development that is perhaps more surprising".

Moreover, it must be stated that simply rolling out of massive amounts of infrastructure is not the most appropriate cure to underdevelopment. Numerous studies have shown that telecommunications is necessary but not sufficient for rural development (Hudson, 1999). Telecommunications infrastructure by itself will hardly promote development. However, one cannot emphasise adequately the significant role of telecommunications in rural development. There are several concerns associated with the need for improvement of rural telecommunications. It is therefore not possible to determine the facts without carrying out some detailed analysis. It is the author's view that the deployment of rural telecommunication services is a necessary step towards the provision of information with respect to the improvement, or lack thereof, of rural development in a given area.

The next section will first present some points to explain the need for telecommunication services in rural areas followed by a discussion of telecommunications-intensive applications that will be used by rural communities to improve their economies and their quality of life.

2.3.2 Telecommunications applications for the wellbeing of rural communities

A great deal of time, effort and study are spent on the provision of telecommunications in rural areas of developing countries, which has been of interest to everyone to convey a message over great distances or know what was going on somewhere. Further, telecommunications have been proven to be the fastest medium to access services and hence the following are some points that may briefly explain the need to such services:

- According to an ITU worldwide survey on rural communications more than 2.5 billion people (about 40 per cent of the world's population) live in rural and remote areas of developing countries where access to telecommunications is still very limited, and, of the small fraction that has any access to telecommunications, radio broadcasts and voice telephony have traditionally been the main services provided (ITU, 2004);
- The issue of communications for rural and remote areas is critical to the ITU membership. From the Valletta Action Plan (1998) to the Istanbul Action Plan (2002) — and the Plan of Action of the World Summit on the Information Society (WSIS) held in Geneva in December 2003 — policy statements and recommendations have confirmed the need to promote basic telecommunication, broadcasting and the Internet as tools for development in rural and remote areas (ITU, 2004);
- Telecommunications networks can provide greater access to various educational opportunities, through distance learning, and medical services, through enhanced videoconferencing between doctors in rural and urban areas (Parker, 1996);
- Rural communities no longer have the people, skills and resources necessary to enhance services. This decline in rural population caused by technological change, urges the timely need of telecommunications for easy information access, thus keeping the rural inhabitants who leave to seek better paying jobs in urban areas; and
- Providing access to reliable telecommunication services in rural areas is important to help overcome a range of disadvantages associated with isolation and low density economic activity (McClelland and Berendt, 1998).

Several different types of specific telecommunication-intensive applications that can help improve the economy and quality of life of rural communities are listed below (Barr, 1998 and Parker, 1996):

- Local Area Networks (LAN) and Wide Area Networks (WAN) that electronically link the parts of an organisation together, improve productivity in the businesses and other organisations so connected. External electronic networks connecting businesses to their suppliers and customers permit cost reductions and service quality improvements, such as online banking and e-government. In contrast, the government and any other appropriate organisation can now obtain census-type and other statistical information electronically from rural and remote areas and this can improve the quality, timeliness of decision making, cost and delivery of services;
- Distance learning networks may be an ideal way for rural schools to pool their resources and to draw on outside skills not available locally, in order to provide their students with the best education available anywhere. With such telecommunications capability, small rural schools can offer advanced courses of maths, science, foreign languages, etc. Moreover, rural residents who cannot afford the relocation or the long drive time required to attend courses in distant locations can enjoy lifelong continuing education using such technology. In the authors view, for many of the residents of the rural and remote areas of developing countries, this capability has the potential to open a broad spectrum of new educational and training possibilities;
- Telemedicine networks can improve the quality of rural health care by permitting medical specialist in distant urban medical centres to consult with rural patients and primary health care providers. Improved remote diagnostic and monitoring capabilities may improve home health care services for rural residents. Nowadays, instead of having to move either the patient to the doctor or vice versa, it becomes possible to move only the relevant medical information that includes medical readings, records, files, etc. Experience has demonstrated that valuable telemedicine applications include in-service coaching and training of remotely located health care staff;
- The Internet has evolved as an important business opportunity for rural businesses seeking to expand their markets. However, with the lack of a local Internet provider who can offer a network server, that avenue of growth is blocked for them. Rural residents, especially in developing countries, who can access the Internet, are privileged;
- Current generations of personal computers equipped with add-on hardware and software can serve as desktop videoconferencing terminals that permits voice and video communication between distant humans. This capability is likely to be more

valuable in rural communities than in urban ones because of greater savings in travel costs. Unfortunately, the telecommunications networks necessary for this application are still rare in rural areas of developing countries;

- Rural telecommunication facilitates finding markets for farm products, fishery catches and handicraft products, negotiating prices and quantities, arranging for pickup and delivery, etc. It also allows access to databases and provides information on distant markets, consumption trends, and future markets;
- Tourism is a rapidly expanding industry worldwide, and offers a significant commercial opportunity for many developing countries. However, such industry is just not feasible without adequate telecommunications, which are essential in developing the business, in promoting it, and in making the reservations and many other detailed arrangements that this industry requires; and
- Some developing countries are facilitating rural community access through telecentres installed in a community centre, library, school, post office, coffee shop, or any other accessible location. They include information and communication technologies such as telephone, fax, and internet access. Therefore, amongst many other things, such centres allow emigrants to keep in touch with the family and friends that they have left behind in the rural villages, promoting profitable revenues from long distance calling charges.

2.4 Telecommunications access

This section will present a brief account on telecommunications access, focusing on universal access to rural telecommunications.

Expanding access to telecommunication services is one of the critical challenges facing many countries as they seek to close the digital divide — especially between urban and rural service availability. Access is a broader concept that involves the following components (Hudson, 1999):

- Infrastructure: Extension of the network to customers;
- Services: For instance Plain Old Telephone System (POTS), value-added, broadband services, etc.;
- Affordability: Pricing of installation, monthly service, local and inter-exchange calls, etc.; and
- Quality: Line quality, network reliability and blockage.

2.4.1 Universal access to rural telecommunications

A rural subscriber gets access to dialup internet service when those living in most urban environments and small cities are already enjoying broadband services. This is indicative of a worldwide trend where rural and remote telecommunication infrastructure and services lag behind urban ones. It is also the reason why investments in telecommunication services in these areas tend to involve some sort of donor or governmental incentive programmes (Ramirez and Richardson, 2005). Such are usually characterised as 'universal access' programmes.

"Universal access typically promises availability of telephone services to most of the nation's residents. However, it does not only mean the availability of telephones in most or all homes; rather, it could refer to access to telephones at community centres or what is referred to as telecentres or even multi-purpose community telecentres" (Hudson, 1999) .

It should be noted that the phrases 'universal access' and 'universal service' are sometimes used interchangeably. According to Onwumechili (2001), some scholars have attempted to differentiate universal access (i.e. access at a reasonable distance) from universal service (i.e. service to each household). However, several policy makers either use the concepts interchangeably or view them as the same.

The ITU, as well as several countries, have also prioritised universal access after studies found that telecommunications positively supported development activities in several sectors such as agriculture, health, social services, and education. Since universal access is to provide access to telecommunication services and facilities at a convenient central location in each community, the range of services offered has to meet the needs of each. Both the types and quantity of services offered will increase as demand grows, and new applications and opportunities emerge (Hudson, 1984; Int'l Commission, 1984; Saunders, Warford, & Wellenius, 1994, adapted from Onwumechili, 2001).

Facilitating access by ever–wider segments of society was the result of decreasing costs of increasingly powerful, reliable hardware and software, as well as the fact that much hardware has become a desktop item. This will continue to drive the use of communication technology. However, the benefits can only be gained if gains in physical access are accompanied by capacities to utilize these technologies for individual and societal development through dissemination of appropriate applications (Nepal, 2005).

The ITU Maitland Commission that was established in 1983 to suggest remedies for the huge telecommunications gap between developed and developing countries, called for a telephone "within an hour walk" throughout the developing world. Since, access to telecommunication services is crucial for socio-economic development, 'universality' should not be assessed only in terms of the number of individuals that have access to telecommunication services, but also in terms of the community and institutions such as schools, clinics, libraries, community centres, etc. (ITU, 1985).

2.4.2 Universal access myths

To guarantee that the rural and developing regions enjoy the benefits of universal access, telecommunication policies need to be based on a rational basis and not simplistic generalisation. It is suggested that policy-makers must rethink long-held assumptions and myths about telecommunications in rural areas. Some such myths were highlighted by Hudson (1999):

- Build it and they will come: In this strategy, the assumption is that the investment in telecommunications alone will lead to economic development. However, several studies have shown that telecommunication services are necessary but not sufficient for development. In fact, many other factors contribute to rural economic development, including other infrastructures (e.g. electrification, transportation, etc.), skilled workforce, and the cost of operations including facilities and labour;
- Rural demand is very limited: Planners of universal service policies may assume small demand for telecommunications in rural areas. Such forecasts are based on the sparse population densities compared to those that are found in urban areas, joined with the misleading notion of "one-size-fits-all";
- One-Size-Fits-All: Many people implicitly assume all rural residents have lower incomes and thus lower demand for telecommunication services compared to urban areas and that all rural customers have similar needs. Individuals and families are likely to have different communication needs from rural businesses and organisations. However, those institutional customers may differ in their service requirements and traffic patterns. Operators who adopt such a strategy may limit choices for rural customers and subsequently limit their own revenues;
- Rural benchmarks must be set lower than urban benchmarks: Planners frequently approach the issue of rural telecommunications policy from the perspective that "something is better than nothing" believing that providing the minimum of services is a technically feasible, economically justifiable target for rural areas. Nevertheless, cutting edge technologies such as terrestrial wireless, Very Small Aperture Terminals

(VSATs), and digital compression, along with design and operations adapted for local conditions, can significantly reduce costs and increase reliability of rural telecommunication networks; and

- A carrier of last resort is the best means to ensure rural access: In some countries, the key operator is acting as a "carrier of last resort" with a Universal Service Obligation (USO) to provide rural service in case no other carrier has done so. Such a carrier is entitled to a subsidy to provide the service based on its cost estimates. However, this policy can be incorrect if there is no incentive for the carrier with the USO to use the most appropriate technology and to operate it efficiently. It can also create a monopoly since the dominant carrier is protected from competition because it has additional costs and obligations not required of new competitors. If subsidies are provided to serve high-cost areas, they should be made available to any operator willing to provide the service, rather than relying on a single carrier of last resort.

2.4.3 Universal access principles

APEC (1994) presented the following universal access principles to provide guidance on how Asia-Pacific Economic Cooperation (APEC) economies accomplish universal access to telecommunication services in line with the established legal, regulatory environment and government structure of each economy. These guidelines are also worth mentioning for their importance to non-APEC regions (APEC, 1994):

- Extension of basic telecommunications access is recognised as fundamental to economic development.
- Each economy will decide on the scope of its own universal access objectives according to its own circumstances.
- The evaluation of universal access objectives should take account of the broad economic and social benefits and the corresponding costs of limited access.
- The telecommunications regulatory framework should:
    - Be administered independently from service operators in order to champion the interests of users;
    - Encourage rational competition so that market-driven network development has the greatest opportunity to flourish; and
    - Provide the kind of certainty in the market that encourages maximum private investment in the network.

- The policy framework for universal access should encourage:
  - The private sector to use innovative bases for generating and calculating revenues;
  - Governments to consider using communication technology to deliver services both for the cost benefit to the government budget and for the intangible benefits to the people of strengthening the communications network;
  - The universal service providers to minimise the costs in providing universal service without compromise on the quality of service; and
  - Equitable sharing of the net universal service costs among the relevant contributing parties. The obligation in supporting the provision of universal service should not affect the relative competitiveness of the operators and service providers in the telecommunication market.
- To be sustainable in the long run, universal access must be provided on a basis that is independent of implicit cross-subsidies. Therefore, revenues should be arranged so that net costs are met through one or more of the following mechanisms:
  - Requiring the provision of universal access as part of the conditions of the licenses of carriers;
  - Mobilisation of diverse capital resources, including public, private and foreign capital;
  - Commercial arrangements negotiated against the backdrop of competition laws; and
  - Transparent funding mechanisms to channel resources to universal access providers, consistent with members' international commitments and other policies.

The following section highlights the challenges and importance of various factors that face planners and designers of rural telecommunications infrastructure.

2.5 Factors affecting rural telecommunication infrastructure

Just as it would be impossible to construct a building without a solid foundation, so too would it be impossible to deploy telecommunication infrastructure without a solid knowledge base. It is necessary to fully understand the myriad, complex matters that abound telecommunication, particularly rural. Getting advanced telecommunication services to rural areas and having them adopted and used will, however, take a long time years in many cases. While the estimates vary, the dominant perception is that rural areas for a variety of reasons will lag behind urban in gaining access to advanced services.

Delivering affordable and accessible services to populations with very low disposable incomes and general lack of capital to acquire telecommunication equipment is a complex challenge. For many rural areas, ancillary services such as electricity supply are simply non-existent or insufficient. Actually, many of the problems facing rural areas are outside the scope of telecommunication alone to resolve and require coordination of rural electrification, transport network development, education and training programs (Andrew and Petkov, 2003). Thus, the deployment of telecoms infrastructure entails a great understanding of its complexities. Its complexity affects people, organisations and institutions at all levels of the society. It is thus essential to consider the readiness of the areas in terms of physical attributes, resources and manpower. This requires expertise on different disciplines, including design, construction, and equipment installation and testing.

The most effective way to manage this complexity is to apply project management expertise that can handle every aspect of the entire job. Besides, the deployment of rural telecommunications infrastructure involves the amalgamation of technologies and systems to make efficient transmissions possible. Hence, there is a need to design more cost-effective technology solutions considering the needs and economies of rural communities. Extensive data from across the regions of the world should help examine the means to address the critical challenge of providing connectivity to rural and remote communities. The complexity characterising the provision of rural telecommunications in developing countries will, hopefully, become clear as some of the various challenges, key issues and problems facing planners and designers when selecting and deploying rural telecommunication infrastructure are outlined in the following subsections.

2.5.1 Technological factors

Infrastructure technologies such as telecommunications, electricity distribution and those that relate to the built environment do not provide just modern conveniences, but play a major role in shaping societies. The physical manifestation of the benefits of rural telecommunications technology may be easily quantified, but the real interactions between the technology and the communities it serves can only be understood as abstractions (Singh, 1991). The task of provision of rural telecommunication services with respect to technological issues constitutes a major challenge if technology is regarded as part of a programme of social intervention in a rural community. “Rural areas have their own unique features and would therefore, require their own unique solutions” (Andrew and Petkov, 2003).

Some of the impacts of technological factors on the choice of appropriate technologies for rural access that will provide the most efficient network and most effective system within the constraints of distance, physical terrain and low population densities are:

- In dealing with uncertain environments, especially with regards to the parameters that are required for efficient and effective technology design and selection including sustainable maintenance complicates the choice of rural technology, because it will be heavily weighted in favour of key issues to be taken into consideration, such as equipment with low fault, low maintenance cost (simple maintenance) and no on-site repair work. For example, Fibre optic cable installation and maintenance will be very difficult and therefore the incurred expenditures will be huge for rural Fibre deployment;
- The uniqueness of rural areas makes it impractical to find a technology that will provide the optimum reliability for all such areas. For instance, an infrastructure provider can build a great deal of additional reliability into a transmission system by replicating components and removing single points of failure. The use of redundancy and remote fault rectification in rural telecommunications networks are possible reliability enhancing techniques. This is even essential in managing the large distances between major centres and the ease of troubleshooting of remote telecoms units. However, this is not always a cost-effective way of building and deploying rural networks, and so this very much depends on the provider strategy. Over and above basic reliability, rural networks would need to have features such as diversified routing, to provide safeguards against breakdowns (ITU, 2006);
- A major problem in network design for rural areas or, in any area where there is a total lack of telecommunication services, is the forecasting of telephone traffic and service needs. This is due to the lack of suitable information such as reliable rural tele-traffic data and the potential growth of subscribers that is usually required to promote network design. Proper decisions have to be made as to whether Plain Old

Telephone Service (POTS) will be sufficient or POTS-plus needs to be available for a region;

- As development increases in a particular rural area, the demand for services will grow; therefore, technology has to cater for a rapid increase in capacity as such demand accelerates. Also, the deployment of technologies must be accompanied by effective human resource development and the use of modular components for ease of maintenance by local people;
- In rural areas of most developing countries, there is a lack of technical support and equipment repair facilities due to lack of skilled manpower. This increases the cost of operation and maintenance of rural systems and therefore, equipment installation and repair become time consuming and expensive;
- The outdoor networks are predominantly overhead and they tend to snap, causing difficulties to subscribers and to service providers. Also, due to stony ground it is difficult to have a good earthing for the exchanges. This issue is frequently encountered, especially in hilly areas, which leads to more faults of card damage due to lightening. Besides, the turnaround time of card repair is more due to long distances and scattered connections.

2.5.2 Physical and environmental factors

Rural areas encompass a range of geographical terrain including forests, deserts, grasslands, mountain regions and isolated islands, this constitutes a primary challenge as difficult terrain, compounded with poor levels of transport infrastructure, increase the cost of establishing, operating and maintaining telecommunication infrastructure (ITU, 2004). Physical factors have to be given proper consideration when planning rural telecommunication infrastructures and services. Some such factors are:

- Parallel infrastructure is necessary to support rural telecommunications needed to stimulate rural development. Without such infrastructures, access to opportunities and advanced services are limited and will have a significant impact on the issue of maximising the benefits. Lesser (1978) earlier noted the importance of complementarity between telecommunications infrastructure and parallel infrastructure capturing the importance of this issue;
- Readily available power sources, accessible roads, transport, etc. are necessary for the installation, operation and maintenance of telecoms networks. For example, power supply is required for the operations of telecommunications equipments. The

unstable/erratic power supply in rural areas is a real predicament and poses a difficulty in running these equipments such as exchanges, because exchanges cannot run on batteries for long hours. There is also the problem of insufficient voltage or over voltage, and to stabilise power at an even level is difficult and costly; and

- Cables are generally laid by the side of roads, but rural areas tend to have no proper roads. Hence, laying down these lines become expensive and difficult. Also, due to the remoteness of rural exchanges, when they develop a fault, it is difficult to send experts to repair them, thus the fault restoration time is lengthier than in urban areas.

Equally important is the impact that technology has on the environmental issues which are receiving more mandatory consideration than ever before. The deployment of rural telecommunications infrastructures and services will not be successful if the relationship between them and the corresponding environmental system is left unconsidered. The international best practices for managing potential environmental impacts in the telecommunications sector is designed to serve as a guideline for sustainable solutions. Rural telecommunications infrastructure providers can therefore implement them to avoid, minimise, and mitigate potential environmental impacts caused by the telecommunications facility construction, operation, and maintenance. Some of the impacts that technology has on the environment are (ITU-D, 2006):

- The laying of cables into the earth or suspended from pole to pole, the erection of radio towers that generate radio and microwave frequencies, and global warming all have an impact on environmental issues. For example, the selection of the sites of towers provides the greatest opportunity to prevent or minimise potential environmental impacts from telecommunications towers. Locating towers on steep slopes or ridges that require access roads up very steep slopes should also be avoided because of potential erosion risks associated with the roads. Consideration should also be given to the visual impact of towers on the landscape and efforts should be made to site towers to reduce visual impacts or use existing infrastructure to install transmission and reception devices (e.g., antennae);
- The general topography of the land constitutes one of the key distinguishing features of rural areas in developing countries which encompass a range of geographical terrain including forest, desert, hills, grasslands, mountain regions and isolated islands. This constitutes a primary challenge as difficult terrain. For instance, in hilly terrains, microwave transmission becomes impossible, because hills can obstruct the transmitting and receiving sites and so, satellite communication becomes a most

commonly used technology despite the overall high cost of such systems as compared with terrestrial wireless systems. Some other options are very expensive due to the high cost of transponder bandwidth;

- The remoteness of the rural area from the nearest PSTN will certainly influence the choice of technology to be deployed and the rollout schedule. Aspects related to location changes have serious implications for planning of rural telecommunications networks. For example, PSTN are designed for specific locations, and when conditions change in such locations, the equipment may have to be moved to other different topographical areas or at least modified. Otherwise, the telecommunication systems will not operate efficiently. The remoteness of the rural areas from the nearest exchange will certainly influence at least the rollout schedule and the choice of the technology to be used. Thus, the need for interworking with new technologies is required to cope with changes in conditions affecting location. For example, the transmission media must also be easy to transport and install in isolated areas, and
- Rural telecommunication networks should have the ability to withstand harsh climatic environments. Factors such as lightning, fluctuations in temperature and wind speed, heavy rainfall or snow will directly affect the provision of telecommunication services. For instance, in extreme weather conditions especially in hilly areas - when it is very hot, 'alternating current' which is a must power supply for the proper functioning of exchanges may not work. Also, in hilly areas, there may be snowfalls causing short- circuiting and power failure.

2.5.3 Economic, social and regulatory factors

Rural areas in developing countries have some economic characteristics that make it difficult to provide telecommunications infrastructure of an acceptable quality at affordable prices without generating losses for operators. Chief among these features are low disposable income and high cost per line for both fixed and wireless technologies in such areas (Hudson, 1984). Therefore, the economics of rural areas is greatly affecting the selection of rural telecommunication technologies and "is the driving force behind the innovation of technological solutions to the problem of access to telecommunications services in those areas" (Gasmi and Virto, 2005). It is essential to look beyond the traditional business and residential access so that costs can be reduced by proper planning, engineering and design of rural networks. The principle of cost effectiveness and logical technological solutions can also be adopted. Some economic issues that need to be considered are:

- Income disparity between rural and urban areas presents major problems for operators attempting to deliver services spanning such economic divides, as it leads to lack of subscriber density in rural areas, which makes investing in telecommunications infrastructure in areas where the economies of scale are just not there for a desirable investment, economically unfeasible and unaffordable (Falch and Anyimadu, 2003);
- The deployment of rural telecommunication infrastructure for the short-term and long term benefits of both the subscriber and the provider requires scarce capital outlay. There is an annual funding shortfall of around US$30 billion for the provision of basic telecommunications in developing countries (Bowry, 1998). The cost of installing and maintaining such infrastructures therefore are likely to be significantly higher on a per subscriber basis than cost of urban systems. The cost per installed line (if one is using copper or Fibre) is inversely proportional to the density of lines per unit area and the income per circuit is lower than that of the urban areas;
- The purchase of new telecommunication equipment that will expand connectivity and last for years has to be cost-effective, which is an essential attribute of the chosen technology so that to be reflected in the layout of the rural telecommunications network to achieve maximum benefits for the invested capital, e.g., reaching greater numbers of people or a greater area of coverage. In addition, the provision of special buildings and facilities for low subscriber densities can make it uneconomical to serve small outlaying villages. As a result, equipment designed for remote locations should be robust and self-contained. Different technologies offer different facilities and since these facilities may not all be capable of quantification in monetary terms, value judgements are necessary (Chasie, 1976);
- Despite the price reductions made possible by new technologies, the cost of installing rural telecommunication networks will remain substantially higher than that of installing urban networks and as is normal, the cost of local switching equipment per access line served in rural areas is many times more than that in urban areas for the same grade of service (Falch and Anyimadu, 2003);
- The suppliers of the financial resources that are required for the deployment of the telecommunications infrastructure are interested in the return on capital investments because such infrastructures are expected to pay for themselves, unlike roads and water (Bowry, 1998). If the investment is unprofitable in the long run, it is unwise to invest in it now; decisions on investments, which take time to mature, have to be based on the returns which that investment will make. The cost of rural

telecommunications infrastructure in relation to projected revenue streams will influence investment decisions. The return on investment is therefore directly related to the degree of risk and the policy framework;

- Telecommunication planners often believe that providing the bare minimum of services is a feasible and justifiable aim for rural areas. New technologies such as the wireless local loop, VSATs and digital subscriber loops together with the right kind of planning can reduce costs, increase reliability, and ensure a higher usability of service. However, policy makers and planners have to ensure the realisation of the goals of this infrastructure by paying careful attention to the rural communities' nature of the demand for services. A healthy supply of telecommunications infrastructure and a variety of services will create the desirable demand (Chasie, 1976);
- The small scattered population in rural areas all make it very costly for commercial operations. Alternate means of providing service to these areas need to be investigated. Previous experiences in some developing countries revealed that population density is far more important than the size of a rural area for the technology selection process. Moreover, the need to adapt the planned infrastructure technology to meet future unknown needs which are unknown is a major issue as one has to deal with changes in the time domain, such as inaccuracies in forecasting subscriber requirements. This tension becomes even more difficult to resolve when one considers what range of services should be provided. The challenge remains, how to make rural areas as attractive to network providers as more densely populated areas? (ITU, 2006); and
- The indirect benefits of rural telecommunications may more than justify the costs and must be taken into consideration in planning and selection of rural telecommunications systems. There is a problem of uncertainty in that even if planners are willing to consider the indirect benefits, it is not always easy to predict and quantify them and one has to make sure that appropriate technology and services are provided while the urban kind of competition should not be an expectation for rural areas (Hudson, 1984).

In order to provide a tool that can be effective in supporting rural telecommunication services and use, one must consider socio-economic issues and provide answers to the following question: What social interaction norms must be observed in the use of the system and how will this be accommodated in system design? One must also understand the social norms that surround these processes. For example, a community's decision-making may traditionally be the function of community leaders. Thus, the success of systems that support community information seeking and use hinges on the abilities of the system's designers to understand how social norms affect the creation, use and sharing of information (Nnadi and Gurstein, 2007).

The provision of a telecommunications network in rural areas may seem unprofitable. However, the immediate social benefits can justify such "unprofitable investment". The value that will be added to the education and health sectors and subsequently to the standard of living of the residence cannot be measured purely in monetary terms (Singh, 1991). Some of the sociological issues that can have a real bearing on telecommunication services are (Singh, 1991):

- The impact of the tensions common in some particular geographical areas in developing countries poses social faction on rural telecommunications service. Preference given in the allocation of telecommunications service to one group over another has often caused bitterness and led even to destruction of telecommunications equipment and the isolation of the network operator from certain communities; and
- Compared to laying cable, wireless technologies can simplify installation in remote locations. However, wireless systems require a local power supply where the theft of solar panels installed to power wireless local loop equipment, and also the theft of copper cables, is posing a major challenge in most developing countries.

Furthermore, the telecommunications sector is highly regulated industry and the choice of telecommunications infrastructure technologies, especially in developing countries, is very often a political decision rather than one based on the most effective solution. Frieden (1997) discussed the business, legal, regulatory and spectrum challenges on the widespread of wireless technologies, some of such issues are:

- The regulatory restrictions on the use of low-cost technologies to provide rural telecommunication services represent a major obstacle to innovative development of such services. Therefore, effective regulations are deemed a necessity and have to be in place in order to deal with critical issues, such as interconnection, tariffs, long distance, local services and competition and licensing.
- The policy environment which usually has the flavour of the political philosophy and which determines the extent and type of coverage together with the speed of rollout of the rural infrastructure will directly influence the selection of technologies and its

associated architectures to be deployed. For instance, the frequency spectrum is regarded as finite natural resource which is subject to intense regulation. However, the regulation is not always friendly to the deployment of telecommunications technologies, especially wireless systems.

2.6 Conclusion

This chapter described rural areas in developing countries as geographically dispersed areas with low population densities, beset by lack of infrastructure including unreliable or complete lack of electricity supply, low literacy and poor health conditions and below survival type economic activity. The inhabitants of such areas commonly suffer from social and economic difficulties and have fewer opportunities than their urban and suburban counterparts and therefore many residents are leaving their regions due to these factors. Rural communities need better services to compensate for their geographical isolation and cost of being far from the cities. However, many obstacles stand in the way.

Inherent characteristics of rural areas (remoteness accompanied by inaccessible terrain, low population density, scattered settlements, harsh environments, etc.) mean that they stand a real chance of missing out on the telecommunications revolution. Such challenges confirm that such areas are generally underdeveloped and underserviced. A major challenge to contend with is that the ratio of revenue to cost may be considerably lower because of higher costs and low population densities, and rural incomes are generally lower than the urban ones and so the people are less able to afford telecommunication services.

In summary, three kinds of factors that specify rural environments in developing countries comprise economic and demographic factors, geographic factors and physical factors. All reviewed literature that tackle various issues related to rural telecommunications considered it only as a technical system. Few researchers have shown that rural telecommunication services are a complex process that involves both technical and socio-economic factors. In many developing countries, the provision of proper telecommunications infrastructure remains neglected in rural areas. One of the major differences between urban telecommunications and rural telecommunications is that the question of affordability is not the only real issue in rural areas.

The ITU's most recent report reveals that rural telecommunications services in many countries are growing but still in need of improvement. Planning of rural telecommunication infrastructure should first consider the development of rural areas as an essential part of a coordinated evolution in a given country. Moreover, "the enhancement of rural telecommunication systems and services through support for building of infrastructure, advising on appropriate institutional structures, assisting in mobilizing financial and human resources, and applications of new technologies, all have the central objective of achieving universal access to telecommunication and information services" (ITU, 2004).

Expanding access to telecommunication services is one of the critical challenges facing many countries as they seek to close the urban/rural digital divide in which a rural subscriber gets access to dialup internet service when those living in most urban environments and small cities are already enjoying broadband services. In this chapter, universal access myths and principles were discussed. Several studies found that telecommunications positively supported development activities in numerous sectors such as agriculture, health, social services, and education.

The various challenges, key issues and problems facing planners and designers when selecting and deploying rural telecommunication infrastructure are outlined in this chapter. Extensive data from across the regions of the world are examined to address the critical challenge of providing connectivity to rural and remote communities. Several factors including technological, environmental, economic, social and regulatory are discussed in this chapter. The analysis is not meant to be an exhaustive treatment of all the challenges facing the planners of rural telecommunications infrastructure but is meant entirely for the purposes of demonstrating that the issues relating to rural telecommunications are multi-dimensional and may in fact be pertinent to a particular deprived area.

In conclusion, one can argue that for successful provision of rural telecommunication infrastructure, several diversified factors that affect the deployment of such infrastructure have to be taken into consideration when selecting telecommunication systems. A contention of this thesis is that an appropriate MCDM approach to rural telecommunications infrastructure selection will contribute to the resolution of some of these issues.

3. TOWARDS A MCDM APPROACH TO RURAL TELECOMMUNICATION

3.1 Introduction

Decision making for multiple criteria problems related to telecommunications networks takes place in an increasingly complex and turbulent environment characterised by a fast pace of technological evolution, substantial changes in available services, market structures and societal expectations, involving multiple technology options. It is a remarkable topic for exploration and application (Granat and Wierzbicki, 2004).

In moving towards the research aim, this chapter reviews the current practices in planning approaches to rural telecommunications. A particular focus is given to the ITU recommendations. It then explores the past research cited in the literature in relation to rural telecommunications infrastructure planning. For the purpose of this chapter, the most general and widely recognised model of decision making process proposed by Simon (1997) will be introduced.

To cover the background deemed necessary towards using a MCDM approach to the selection of rural telecommunications infrastructure, an investigation of the various MCDM approaches and their underlying theory will be conducted in this chapter. The classification of MCDM methods will also be discussed, focusing on the need for such methods to the problem at hand. In addition, a comparison of several MCDM methods based on the literature review will be given. A particular emphasis is given to discuss several AHP/ANP drawbacks, which have caused emergence of substantial criticisms from many papers identified from the literature of both methods.

The succeeding section reviews the literature related to the applications of the AHP/ANP in rural telecommunications planning and design in terms of decision making. An account on the applicability of the SSM to the selection of rural telecommunications will be given and a conceptual model will be developed. Finally, the chapter concludes by further elaborating the research methodology outlined in chapter 1, emphasising the research philosophy, approach, strategy and design, and methods used in this study.

The following section will present an account of the current planning approaches to rural telecommunications infrastructure.

3.2 The current planning approaches to rural telecommunications

Generally, research in the area of telecommunications, in particular rural telecommunications planning practice, traditionally has and still focuses mainly on the technological engineering aspects (ITU-D7, 1998). This is because it was and still left largely to engineers, many of whom work on advancing and improving the technology. The ITU, which is responsible for recommending world standards amongst other things for the telecommunications sector has made considerable recommendations in relation to the planning and implementation of national telecommunication development plans for rural and remote areas. From a technicality point of view and to be economically attractive, the ITU recommends that rural telecommunications systems should satisfy the following conditions (ITU-D, 1997):

- Low capital and operational costs;
- Low power consumption and simple maintenance;
- Easy installation and minimum field alignments;
- High reliability and easy to expand;
- Ability to withstand harsh climatic environments;
- Meet the present and expected future demands; and
- No active air conditioning required.

However, there is no single technical solution suited to all situations and the development of rural networks calls for a conventional technical solutions such as copper wire, radio transmission, and sophisticated solutions such as optical fibre systems and satellite small earth stations. This blend is dictated by a number of basic parameters, such as population density, terrain, distance, power supply, network configuration, etc. Therefore, each individual country has to be given special detailed consideration, and systems must be selected to suit its particular situation (ITU-D, 2006).

Some important reasons for the inadequacy, in many cases, of today's rural telecommunications networks in developing countries are (ITU-D, 1997):

- An underestimation of the role of telecommunications in development;
- Insufficient information on technology and institutional and managerial errors;
- Deficiencies in internal organization;
- Little attention to long-term planning and training; and
- Lack of adequate local manufacturing and financing constraints.

However, rural telecommunications cannot be improved and expanded unless (ITU, 2001):

- Political determination exists and governments recognize the value of enhancing rural development;
- International aid funding is directed towards rural projects;
- Suitable projects are specifically designed for rural areas with both low initial investment and low-maintenance costs;
- Low revenue and poor quality of rural telecommunications can be managed with the help of modern technologies, with specifically designed rural equipment; and
- Improving the rural telecommunications infrastructure by investing more money in it has some very significant multiplier effects on the economy as a whole.

The ITU recommends four models for rural areas based on settlement patterns and physical geographical layout of the area. Sets of appropriate technologies, including network configurations, are then matched to these four models. These four systems are called optimum systems for rural areas (ITU, 1989). For instance, a telecommunication operator usually receives several technology solutions from external vendors. The challenge of matching the parameters of such an engineering problem with the available alternative solutions becomes a challenge to the telecoms engineer in this particular selection phase.

While the above ITU recommended plan refers to the various issues that need to be considered in the selection of rural telecommunications infrastructure mentioned in this thesis, it still does not provide a methodological "technology selection" approach that is suitable to rural and remote areas. At best, this plan calls for some form of planning that goes beyond the traditional technology-only aspects.

The ITU development study group 2 mentioned various issues involved in rural telecommunications such as the economic, social and cultural issues, discussed in chapter two. However, the provision of rural telecommunication infrastructure is focused purely on network issues. There seems to be little or no relation between the issues mentioned earlier in the report and the infrastructure planning aspects discussed in the later part of it. The outcome is roughly a set of recommended instructions for configuring telecoms network infrastructure (ITU-D, 1997).

The ITU recommended PLANITU which is a software planning tool for the optimisation and dimensioning of telecommunications networks. Figure 3.1 gives a concise but clear overview of the functional architecture of the PLANITU. It includes a more "integrated and interactive" approach for finding minimum cost solutions for various building blocks of the network.

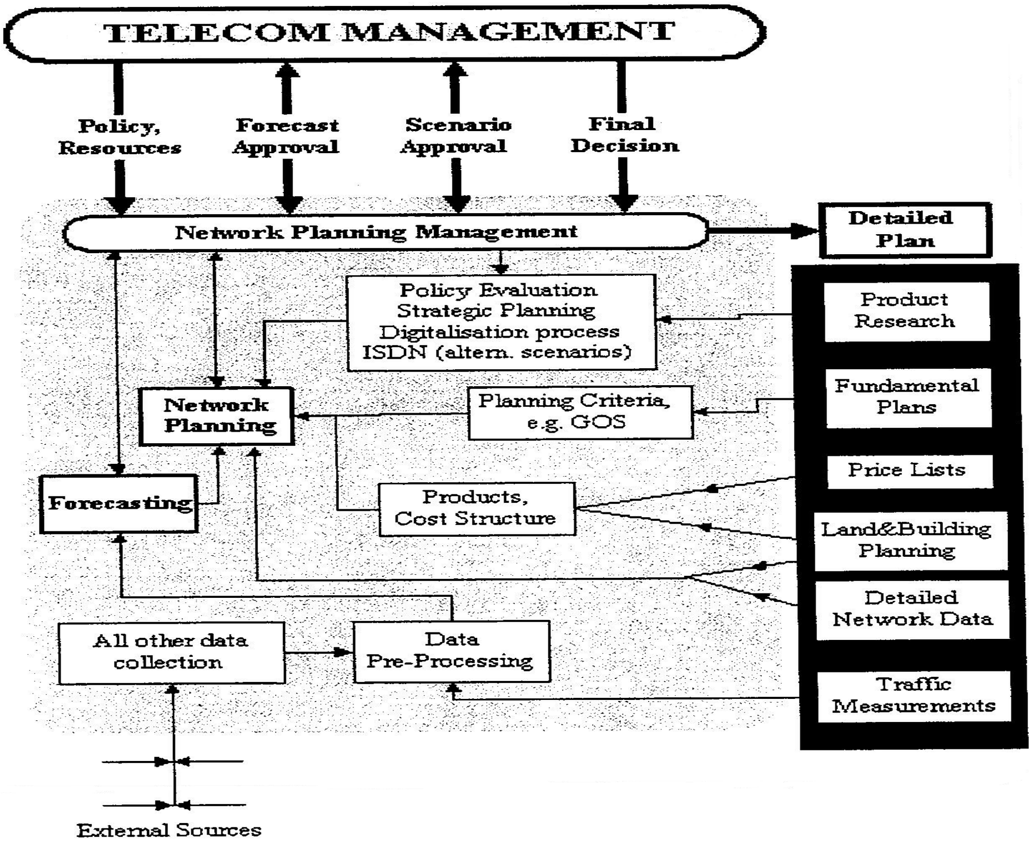

Figure 3.1 PLANITU functional architecture
(Source, http://www.itu.int/itudoc/itu-d/dept/psp/ssb/planitu/plandoc/index.html)

The processes reflect the planning activities carried out by worldwide network providers or telecommunications operators. The various categories of data as reflected on the diagram are used to investigate various network scenarios against the criteria of "minimum cost solutions". In general, the focus is on network planning which is not the same as planning and design of telecommunications infrastructure. The complex issues pertaining to rural areas such as those discussed earlier in chapter two are not given sufficient attention. It is therefore concluded that the planning process that is implied in PLANITU is linear lacking an in-depth investigation of the problem situation with respect to rural telecommunications planning for a particular rural area. Even when one analyses the approach that the local telecommunications operator currently uses to deal with such problems, the general trend seems to be only consider those aspects that directly affect the network configuration (Smith et al., 2000).

The rural telecoms infrastructure selection process according to the current rural planning processes and procedures recommended by the ITU, discussed above, was treated as pure technological system. Hence, if one were to go beyond the objectives of PLANITU to a higher level of planning then the Systems Engineering (SE) methodology could fittingly be examined to embody current practices. The SE was developed in 1940s through practice at the Bell Telephone Laboratories in the US. It is concerned with the planning, design, construction, evaluation and maintenance of large-scale systems that may involve both machines and human beings (Flagle et al., 1960). Hall (1969) reported that SE has three broad dimensions:

1. The knowledge and information dimension, which emphasises the need for an integration of specialised knowledge from different disciplines;
2. The time dimension, which is related to the chronological phases that entails program planning, project planning, system development, production, installation, operation and retirement; and
3. The logic dimension, which is related to the process of problem formulation, value system design, systems synthesis, systems analysis, optimisation of each alternative, decision making and planning for action to implement the next phase.

In the application of SE to the planning of rural telecommunications, it is dominated by the time dimension. The whole approach places an emphasis on defining a range of definite objectives usually achieved by means of trade-offs, so that the performance of the system can be determined accurately. It should be emphasised that the various sequences or steps should not be followed such that each phase is completely carried out before moving on to the next one. The SE has been successful as a methodology for telecommunications turnkey projects that dealt with the provision of services (Andrew and Petkov, 2003). However, the author believes that when it comes to large engineering projects where the key purpose of the intervention is to improve the quality of life, such as rural telecommunications and electrification in developing countries, the SE methodology poses serious limitations that render it inadequate to cope with the issues and challenges associated with rural telecommunications, such as those discussed in chapter two, which aim to promote development.

Another practice that falls within the developmental and integrated domain to rural telecommunication was promoted by Hudson (1984). However, she only raised several questions for consideration in the choice of rural telecommunications technologies. She provides no enabling planning methodology, model or framework that can enhance such a technology selection process.

Other authors, Andrew and Petkov (2003) defined rural areas as complex settings where the planning of telecommunications infrastructure for such areas is characterised by not having a clear beginning or an end, by involving soft and hard data and most importantly the multiple stakeholders including the human element. Thus, if all the stakeholders are to benefit, the issues involved in the planning are not always technological but technology comprise just one subsystem of the overreaching complex rural telecommunication system. They recognised that such problems incorporate many tangible and intangible factors; some of them are technical in nature while others are soft, involving social, cultural and political aspects. Eventually, they applied some systems thinking methodologies, such as Soft Systems Methodologies (SSM) for the planning task. A brief discussion of the SSM will be presented in section 3.4.

The above discussion of traditional approaches and past research cited in the literature in relation to rural telecommunications reveals that the existing approaches, apart from the systems thinking, do not address the problem of rural telecommunications infrastructure selection holistically. Those current practices are therefore not comprehensive enough for the choice of the most appropriate rural telecommunications technologies, which is a primary function of telecommunications planning, for it is the planning stage that can determine the appropriateness and effectiveness or the success or failure of a newly deployed rural telecommunications.

The research reported in this thesis aims to overcome the shortcomings inherited in the abovementioned current approaches by using a broader multicriteria analytical approach, in particular the ANP, which aptly characterises current practice. It eventually proposes a decision model for the selection of such rural technologies. Embedded in the primary contention of this thesis is that the suggested model has to cater for more than the technical engineering aspects.

For the purpose of this chapter, the next section will briefly overview the decision making process followed by an introduction to the MCDM methods. For detailed discussions of these methods, one can refer to Triantaphyllou (2000).

3.3 The Decision making stage

The true goal in decision making is the ability to look into the future, and to make the best possible decision based on past and present information and future predictions. In case of development, this means the risk and vulnerability of populations and infrastructure to hazards. This require that data be transformed into knowledge, and that the consequences of information use, decision-making and participatory processes, be analysed carefully. Broadly speaking, this involves making a selection from a set of alternative choices on the basis of more complete information and analysis. The research on quantitative and quality decision-making has made significant progress with the transition in theory from single criterion to a decision support science. It has more focus on realistic situations involving several decision-makers, thus resulting in complexity of evaluation and selection among a set of alternative elements. The most general and widely recognised model of decision making process proposed by Simon (1977) categorized the decision making process into three phases:

1. Intelligence phase: in which the decision maker/s examines the economic, technical, political and social environment to identify the new conditions that call for new actions.

2. Design phase: in which the decision maker/s designs and develops possible courses of action. This includes the formulation of a model, setting the criteria for choice and searching for alternatives.

3. Choice phase: in which in traditional terms the decision is made, i.e. the decision maker/s selects the best alternative.

A fourth stage, Implementation, was later on added by Simon to the above process. "Successful implementation results in solving the original problem, while failure leads to a return to the modelling process" (Petkov and Petkova, 1998). This situation fits well the selection of rural telecommunication technologies as one could clearly identify the intelligence, design and choice phases. The former two phases are more complicated than the latter phase as they require a mix of expertise and so called problem structuring techniques (see Rosenhead, 1989).

3.3.1 Overview of MCDM methods

The MCDM field (also sometimes termed multiple criteria decision aid or multiple criteria decision analysis (MCDA)) is the study of methods and procedures which concerns about multiple conflicting criteria can be formally incorporated into the management planning process. It is one of the most well known branches of decision making, which has evolved over the last three decades as one major discipline from the field of operations research. Its techniques are described as a set of approaches that can help individuals or groups in researching important complex decision-making problems. Their aim is to guide the decision-maker in determining the course of action that best achieves the long-term goals, by providing the decision-maker with some measure of consistency (Stewart, 1992).

The motivations for multi-criteria approaches to decision making emerged from the drawbacks of the traditional approaches to the study of single criterion decisions (undertaken by one person in one place and time) (Banville et al., 1998). Liao (1998) observed that in complex decision-making situations, several interrelated tasks have to be addressed simultaneously to reach an overall objective. The development of MCDM techniques originated from the recognition of the multi-criteria nature of managerial decision tasks as well as the increasing power of computers (Kotteman and Davis, 1990).

MCDM network representation of the real world allows the decision problem to be viewed within a larger environmental, organisational and political context. The interrelationships among the various criteria that affect the decision problem are better represented by network multicriteria models (Saaty, 2005). There is a need for approaches that combine available quantitative data with the more subjective knowledge of experts. Decision-theory techniques applied by high-end knowledge professionals have been successfully used for contrasting expert judgments and making educated choices. The field of MCDM, by coupling theory and knowledge, provides an analytical approach to expert consultation and is adapted for a variety of technology aiming at sustainability assessments. A collective effort is made to provide a universal toolset of methodologies capable to handle decision problem complexity.

The appropriate "objective" analyses cannot relieve decision makers of the responsibility of making difficult judgements. It is an aid to decision-making, which seeks to integrate objective measurement with value judgement and to manage subjectivity. The latter is evident particularly in the choice of criteria and in determination of their weights. In this choice, one can introduce some of the MCDM methods because they have already turned out to be applicable in business practice. The following facts contribute to their applicability in solving complex problems (Belton and Stewart, 2002):

- The aim of MCDM is to help decision makers learn about the problem, express their judgements about the criteria importance and preferences concerning alternatives, confront other participants' judgment, understand the final alternatives' values, and use them in the problem solving activities;
- MCDM methods do not replace intuitive judgement or experience and they do not oppress creative thinking; their role is to complement intuition, and to verify ideas and support problem solving; and
- In MCDM, one takes into account multiple conflicting criteria to aid decision-making. One can compare different methods and assess their convenience in problem solving. The most useful one are conceptually simple, transparent and computer supported.

MCDM methods should be approached systematically. The phases of decision-making processes that are commonly acknowledged in literature such as that presented in section 3.3 have to be followed (Belton and Stewart, 2002): from identification of a problem, through problem structuring (model building), its use to inform and challenge thinking, to the creation and analysis of an activities plan to solve a problem (e.g. to implement a specific choice, to suggest a recommendation and to monitor performance) (Cancer and Mulej, 2006b).

The next section reviews the literature in relation to the classification of different MCDM methods.

3.3.2 Classification of MCDM methods

There is no uniform classification of MCDM. Thus, there are many ways to classify them, such as form of model (e.g. linear, non-linear, stochastic), characteristics of the decision space (e.g. finite or infinite), or solution process (prior specification of preferences or interactive). Lai and Hwang (1994), Henig and Buchanan (1996) and Zimmermann (1996) provide a broad classification of the field into two categories:

1. **Multiple Objective Decision-Making (MODM):** MODM studies decision problems in which the decision space is continuous. It is therefore not associated with problems in which alternatives have been predetermined. The decision-maker's primary concern is to design a most promising alternative with respect to limited resources. A typical example is mathematical programming problems with multiple objective functions. Kuhn and Tucker (1951) were first to make a reference to such a problem, which is also, known as the "vector-maximum" problem.
2. **Multiple Attribute Decision Making (MADM):** MADM is associated with problems with discrete decision space, in which the set of decision alternatives has been predetermined. The decision-maker is to select/prioritise/rank a finite number of courses of action. Some authors like Lootsma (1996), use the term MCDA instead of MADM to indicate its links to classical decision analysis. However, "very often the terms MADM and MCDM are used to mean the same class of models (i.e., MCDM)" (Triantaphyllou, 2000).

Saaty (1990) and Lootsma (1996) observe that MCDM includes three general groups of approaches:

1. **Multi Attribute Utility Theory (MAUT)**: refers to one of the most widely applied sets of multi-criteria methods, known as the multi-attribute value (or utility) theory

(MAVT or MAUT) (for a detailed description, see Belton and Stewart, 2002). It has been improved to SMART (a simplified multi-attribute rating approach) and other approaches (for example SWING, SMARTER). They are supported by several computer programs, e.g. HIPRE 3+, Web-HIPRE and Logical Decisions® for Windows;

2. **Analytic Hierarchy Process (AHP)**: in which a complex problem is decomposed into a system of hierarchies (briefly introduced below, for a detailed description see, chapter 4); and
3. **Outranking**: constitutes a class of ordinal ranking algorithms for multi-criteria decision making. Some decision problems do not require alternatives to be ranked with respect to their final values; often it is good enough to find out which of them is the most preferred, i.e., there is a finite number of discrete alternatives to be chosen among and the number of decision criteria/makers may be large. Therefore, this is recommended for such situations. The most widely applied are ELECTRE in more variants and PROMETHEE (for details see Vincke, 1992). Furthermore, interactive methods as another set of multi-criteria approaches emphasise dialogues with the decision maker, who reacts to the first solution provided by the first computation step. These are especially applicable when a complete preference model is not constructed in advance and when alternatives need improvements (for details see Vincke, 1992).

Keeny (1992) considers that MAUT, with some operational assumptions, is an excellent candidate for a prescriptive decision theory. Salo and Hamalainen (1997) state that the AHP has been very successful in gaining the acceptance of practitioners, possibly owing to the helpfulness of the hierarchical problem representations and the appeal of pairwise comparison in preference elicitation. Schoemaker and Waid (1982), after an experimental comparison of five different techniques for determining weights in additive utility models, have found that AHP was perceived as the easiest to use and the most trustworthy of the models tested.

Cancer and Mulej (2006a&b) emphasised that: MAVT, SMART, AHP, ANP, outranking approaches, interactive methods and preference programming, together with adequate computer programs can complement intuition, verify ideas and support their development into innovations. This makes them more acceptable. However, results of MCDM should not be understood as the final "right" answers in the problem solving process. Multi-criteria analysis cannot be justified within the optimization paradigm frequently adopted in traditional Operations Research / Management Science (OR/MS) (Belton and Stewart, 2002).

The AHP method, which was developed by Saaty (1980) and supported with the Expert Choice software, excels by wide applicability and is distinguished by the scales used, the methods used to express judgements about the criteria importance and preferences to alternatives and the manner of transforming these judgements into numerical values. A (relatively, perhaps requisitely) holistic approach (as the opposite of a linear and piecemeal approach) is used in such a method in which all the problem criteria are structured in advance in a multilevel hierarchy. In a comparative analysis of several MCDM approaches, Olsen et al. (1996) concluded that the AHP was considered easy to understand, despite the lengthy eigenvalue calculations needed to derive the local priorities of the elements in the hierarchy, which in fact remain hidden from the end-user through the use of the software.

Furthermore, it is generalised for neural decision processing, the Neural Network Process (NNP). It is completed with the interaction and dependence of higher-level elements on lower-level elements and relations in the form of feedback structure that looks like a network, the Analytic Network Process (ANP), which is supported by the *SuperDecisions*. It overcomes the traditional OR/MS approaches in the context of Systems Thinking, because it allows us to include tangible and intangible factors and both interaction and feedback within clusters of elements (inner dependence) and between clusters (outer dependence).

3.3.3 The need for a MCDM approach for the selection of rural telecoms

The existing literature related to rural telecommunications (see Daniell, 1992; Ramirez, 2000; Andrew and Petkov, 2003; Nepal, 2005) has shown that the provision and/or improvement of rural telecommunication infrastructure involves both technical and non-technical factors. It is considered a major part of an integrated development process, which operates in a complex rural environment. Technology selection approaches, especially in rural environments, are often confronted with the challenge of dealing appropriately with complicated social systems, where a wide (and often ever changing) variety of stakeholders with different values, interests and motives are interacting.

The findings of such approaches often reveal a diverse picture of the reality of a programme/project, particularly when viewed through the eyes of various stakeholders. Therefore, the provision of such services has to be tackled from different perspectives, in which a rural telecommunications system can be viewed as having three discrete interactive components (Nepal, 2005):

1. The technological system (the telecommunications network);
2. The society (the rural community for whom the telecommunications service is intended); and
3. The organisations (the telecommunications service providers, investors, regulatory body, and local/provincial/national government).

These components interact with economic, environmental and other parallel infrastructure factors. Therefore, it becomes clear that when providing rural telecommunication infrastructure, the focus is on non-linear relationships rather than linear ones, dynamic factors rather than stable ones (Begum, 1994). Moreover, a review of the literature revealed that the main existing perspectives in research practice could be identified as (Kazi and Spurling, 2000):

- Empirical practice, which emphasises technology selection activities based on outcomes, and concentrates on the effects of practice as defined in terms of measurable outcomes. Its emphasis is on judging past practice, and based on a hypothetico-deductive approach; it provides a hierarchy of methodologies ranging from single-case designs, which systematically track progress to randomised controlled trials, which enable a causal link to be made between the social work intervention and its effects. These methods are essentially testing procedures providing an account of the content of the interventions that are tested; and
- The interpretivist approaches, which provide an emphasis on participatory evaluation of practice. These approaches tend to emphasise qualitative methods such as ethnography. However, these perspectives tend to be suspicious of outcome-based methodologies, and therefore their focus tends to be one-sided in capturing the dimension of practice.

In analysing the challenges involved in rural telecommunications presented in chapter two, a concise picture of the issues and relationships amongst these issues involved in rural telecommunications can be established. Furthermore, since there are several various stakeholders and multiple criteria involved in rural telecommunications infrastructure selection, there is a need to consider multiple perspectives of the relevant stakeholders involved as well as multiple criteria in the selection process.

There do not appear to be any current rigorous methodology/ies for the selection of rural telecommunication infrastructure that caters for not only the factors and issues involved in the provision of rural telecommunications but also explores the dynamics and interrelationships between them in a systematic way. The planning process and techniques used are very much based on the assumptions of systems thinking. Moreover, the selection of infrastructure is usually made separately in time and space by the politicians, legislators, network providers, accountants and engineers who all have their particular domain and who will try to optimise the solution according to their own domain.

The entire technology selection process is an engineering practice about optimising and deploying the network according to the stipulated time and specifications. The various technology selection decisions are done by experts who would normally have a technology background, and a worldview of the planning situation imposed on them, either by the dictates of the organisation or the industry, or by tradition. Hence, there is rational justification for the selection of technology to be done by the experts and hence a relevant multicriteria methodology that supports holistic intervention in rural areas with respect to telecommunications infrastructure can be used.

MCDM methods can be used to avoid undue simplification and provide useful tools for practical work with complex systems. A holistic approach that recognises the limitations of both empirical practice and interpretivist approaches, and attempts to provide a perspective, which goes beyond the consideration of either outcomes or interpretivist insights, is therefore required. This section therefore explores a MCDM approach, specifically the analytic network process for the selection of rural telecommunications infrastructure.

In Peniwati's (2007) paper, several group decision-making methods were evaluated for effectiveness in terms of 16 adopted criteria. The methods were compared and rated as (very high, high, medium, low, very low, and not applicable) on these criteria. The focus was not so much about identifying and exhaustively summarising all methods of MCDM. Rather, it was to evaluate most of group decision-making methods as summarised by Couger (1995) in terms of their technical merits and subject matter. Some of the methods discussed in this section were compared and contrasted with respect to each criterion, as well as for lack of a better and more general way to structure the problem.

A summary of the results, which was restructured from the paper to illustrate the findings, is given in Table 3.1 below. The results indicate that the AHP and, in particular, the ANP models, demonstrate remarkable performances compared with other methods with respect to almost all criteria. A brief description of some results pertaining to this study is given below, for full explanation, one can refer to Peniwati (2007). Note that *italics* in the following paragraphs correspond to the concerned evaluation criteria.

With respect to *leadership effectiveness*, AHP/ANP are rated high because both techniques provide collaborative tools to enhance communication effectiveness, inconsistency and incompatibility measures that provide feedback to the group members ensuring validity of the outcome, structure to facilitate task division, and the means to balance consensus and voting to obtain group judgements. Regarding *learning*, AHP/ANP are rated very high because both provide a highly summarised description of the problem that facilitates learning beyond membership of the group, allowing one to learn more from their applications. Participants in an experimental study ranked the AHP as the least difficult to apply and the most trustworthy method among those studied (Schoemaker and Waid, 1982).

In terms of *scope*, the AHP, MAUT/MAVT and Outranking do not involve a technique to broaden problem abstraction. However, as analysis enhances problem abstraction, they are rated medium because they are assumed to apply techniques such as NGT or Delphi that are rated medium. For *consideration of other actors and stakeholders*, the AHP/ANP are considered the only methods that facilitate a group in explicitly including other stakeholders' concerns in detail as part of the problem structure and quantifying them, and hence they are rated high. With regard to *scientific and mathematical generality,* in the AHP/ANP, the mathematical foundation is generalizable without additional assumptions, hence, both are rated very high.

The AHP/ANP may begin with brainstorming for what alternatives should be included in the hierarchy/network structures. Hence, both are rated very high on the *development of alternatives.* However, the AHP has certain limitations since not every problem can be defined as a hierarchical model. The extension of AHP allows the representation of more complicated relationships through the ANP, which can handle not just hierarchical but more complex problems involving network structures with relationships between clusters and elements. The influence among the elements does not necessarily have to flow only downwards as in AHP models, but it can flow between any elements in the non-linear network. That enhances the expressive power of the ANP.

As regards *applicability to intangibles*, which are usually more unpredictable than tangibles because they have no scales of measurement, Peniwati (2007) pointed out that a method is rated low if it does not involve quantification of intangibles or if it simply assigns arbitrary ordinal numbers to intangibles; medium if it involves measuring intangibles on an interval scale or a ratio scale or an absolute scale; high if it involves measuring intangibles on an interval, ratio or absolute scale; and very high if its measurement is applicable to intangibles and gives an assessment of their relative importance, either absolutely or relatively, as the user wishes.

The AHP/ANP are rated very high in terms of the inclusion, and measurement, of the multidimensionality of the factors involved, because both methods apply the fundamental measurement scale which is applicable to intangibles, and the user chooses whether to use a relative, ideal or absolute measurement level, as s/he wishes. The fundamental scale of the AHP/ANP is applicable as a tool for comparing tangible attributes with other intangible attributes (Saaty, 2010). As discussed in chapter 4, the process of measuring intangibles in AHP/ANP include either paired comparisons or ratings to prioritize or rate alternatives on a set of criteria arranged in a hierarchical or network structure.

The AHP/ANP uses ratio scales and assumes that the rank preservation principle is sufficient but not necessary. MAUT/MAVT is based on interval scales and uphold the principle of rank preservation as both necessary and sufficient. The outranking method (ELECTRE) uses cardinal scales with dominance concept based on graph theory to determine the best alternative when there is one, and does not assume anything about rank preservation. Bayesian Analysis uses probabilities and relies on statistical estimates of these probabilities when possible (Cho, 2003).

In ANP, the outcome of influence with respect to various control criteria: economic, social, political, etc. is measured and combined for the BOCR respectively and the outcomes for the alternatives are then combined by prioritizing the importance of the criteria in each case. Also, the support offered by ANP for group decision making and the *SuperDecisions* software established it as a powerful tool for consolidating opinions in complex situations that usually involve a number of stakeholders. As illustrated in Figure 1.1, in the current situation for the architecture of telecoms service evaluation and selection, there are several diversified complex external factors affecting each other, thus it is necessary to use the network model for decision-making related to the selection of rural telecoms infrastructure technology.

Table 3.1 Comparisons of group decision-making methods

Method	Criteria	Group Maintenance		Problem Abstraction		Structure		Analysis	
		Leadership Effectiveness	Learning	Scope	Alternatives' Development	Breadth	Depth	Judgments' faithfulness	Breadth & Depth of Analysis
Structuring	Analogy & attribute assoc.	Low	Medium	Medium	Low	N/A	N/A	N/A	N/A
	Boundary examination	Medium	Medium	High	Low	N/A	N/A	N/A	N/A
	Brainstorming	Low	Low	Low	Medium	N/A	N/A	N/A	N/A
	Morphological connection	Low	Medium	High	V. High	N/A	N/A	N/A	N/A
	Why-What's stopping	Medium	Medium	High	V. High	High	High	N/A	N/A
Ordering & Ranking	Voting	Low	Low	N/A	N/A	Low	Low	Low	Low
	Nominal group technique	Medium	Medium	Medium	High	Low	Low	Low	Low
	Delphi	Medium	Medium	Medium	High	Low	Low	Low	Low
	Disjointed Incrementalism	Medium	High	Medium	Medium	High	Low	Medium	Medium
	Matrix evaluation	Medium	Medium	Medium	Low	High	Low	Medium	Medium
	Goal programming	Low	Low	Medium	Low	High	Low	V. High	Medium
	Conjoint analysis	Low	Low	Medium	Low	Low	Low	V. High	Medium
	Outranking	Medium	High	Medium	High	High	Low	Medium	High
Str. & Measuring	Bayesian analysis	Medium	High	Medium	Low	Low	Low	V. High	Medium
	MAUT/MAVT	Medium	High	Medium	High	High	Low	High	High
	AHP	High	V. High	Medium	V. High	High	High	V. High	V. High
	ANP	High	V. High	Medium	V. High	High	V. High	V. High	V. High

Table 3.1 Comparisons of group decision-making methods (*cont'd*)

	Criteria / Method	Fairness			Applicability, Truthfulness & Validity			
		Alternatives' cardinal separation	Prioritizing Group members	Stakeholders consideration	Mathematical generality	Applicability to intangibles	Applicability to conflict resolution	Outcome validity
Structuring	Analogy & attribute assoc.	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Boundary examination	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Brainstorming	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Morphological connection	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Why-What's stopping	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ordering & Ranking	Voting	Low	Low	N/A	Medium	N/A	N/A	Low
	Nominal group technique	N/A	N/A	N/A	Medium	N/A	N/A	Low
	Delphi	N/A	N/A	N/A	Medium	N/A	N/A	Low
	Disjointed Incrementalism	N/A	N/A	Medium	Low	Low	N/A	Medium
	Matrix evaluation	N/A	N/A	Medium	Low	Low	N/A	Medium
	Goal programming	High	N/A	Low	Medium	Medium	N/A	Low
	Conjoint analysis	High	N/A	N/A	Medium	Medium	N/A	Low
	Outranking	High	High	Low	Medium	Medium	N/A	Medium
Str. & Measuring	Bayesian analysis	High	N/A	Low	High	Medium	N/A	Medium
	MAUT/MAVT	High	High	Medium	High	Medium	Medium	Medium
	AHP	High	V. High	High	V. High	V. High	High	High
	ANP	V. High	V. High	High	V. High	V. High	High	High

In conclusion, based on the review of the literature, one can identify MCDM as a suitable approach to understand and analyse problems of this type. Its methodological framework is concerned with understanding complexity in a system and hence suits such complex nature of rural telecommunications systems. In particular, the AHP/ANP techniques are to be considered as applicable potential methods, with particular focus on the ANP to be used as a dominant methodology to fulfil the purpose of this research. To the best knowledge of the author, no previous application of ANP method to rural telecommunication infrastructure selection has been cited in the published literature (Gasiea et al., 2010 and 2009a&b). In order to achieve the main aim of this research, an analytical decision structure for the selection of rural telecommunication technologies will gradually be developed.

AHP/ANP are widely used in practice and they have become a well-known topic in multicriteria research. Regarding the general literature on AHP/ANP, there are a number of publications criticising them, some of which raise controversial issues and debates, a review of which is given in section 3.3.4. A brief account of other existing methods such as soft systems thinking (SSM) (Jackson, 2003) that was previously applied in the planning of rural telecommunications infrastructure as was mentioned in section 3.2 is given in section 3.4. For further details on SSM, one can refer to Checkland and Scholes, 1999; Jackson, 2003 and Flood, 1995.

3.3.4 Comparison of the AHP/ANP methods

1. The Analytic Hierarchy Process (AHP)

The AHP is a special case of the well-known decision theory ANP, which has originally been devised by Thomas L. Saaty, together with computer program Expert Choice (see Saaty, 1990). It has proved to be one of the more widely applied MCDM methods (Zahedi, 1986). The AHP derives ratio scale priorities for elements and clusters of elements by making paired comparisons of elements on a common property or criterion. It has long been used in dealing with complicated decision-making problems by breaking down a complex, unstructured situation into its component elements; arranging these elements into a hierarchic order; assigning numerical values to subjective judgements on the relative importance of each element; and synthesising the judgements to determine the priority of elements (Liao, 1998).

The extending applications of the AHP include more sophisticated features, which are: cost-benefit analysis, the forward-backward process and the ANP. The cost-benefit analysis uses two separate hierarchies of costs and benefits respectively to represent the problem so that alternatives can be prioritised with respect to costs and benefits separately. The forward-backward analysis is applied to analyse future outcomes in planning and conflict resolution problems (Alexander, 1997). The ANP will be briefly introduced below and discussed in detail in chapter 4.

Representations of a decision problem using the AHP have several advantages. These include its stability because small changes in the decision have small effects on the outcome, and flexibility, as any additional criteria added to a well-structured hierarchy do not affect its performance (Saaty and Vargas, 1994). In addition, the AHP provides a large amount of information on the structure and function of the system in the lower levels. It can be used to describe how changes in the priority of higher levels affect the priority of criteria in the lower levels. Natural systems constructed as a hierarchy evolve more efficiently than those assembled as a whole and decision makers are able to structure a complex decision problem with the aid of the analytic hierarchy approach, thereby making decision elements and their relationship more visible (Liao, 1998).

On the contrary, a number of weaknesses of AHP include some aspects which have caused emergence of substantial criticisms from many papers identified from the literature. In this section, several types of criticisms are addressed focusing mainly on the major issues. The rank reversal problem is perhaps the most controversial issue in AHP, which was highlighted immediately after the introduction of the method. Many papers written by a number of MCDM researchers have addressed rank reversal phenomenon (e.g., Belton and Gear, 1983; Dyer and Wendell, 1985; Schoner and Wedley, 1989; Holder, 1990; Dyer, 1990; Schenkerman, 1994).

Critics have shown that rank reversal occurs when using comparisons and relative measurement to prioritise criteria and also alternatives on intangible criteria in two ways. First, when new alternatives are added or old ones are deleted. Second, when new criteria are added or old ones deleted with the caveat that the priorities of the alternatives would be tied under these criteria. For example, Belton and Gear (1983) built an example of a simple hierarchy with three criteria and three alternatives, and pointed out that the ranking of alternatives determined by the AHP may be altered by the addition of another alternative for consideration. In other words, after getting the final rank ordering of a certain number of alternatives by using relative measurement of AHP, if decision makers change the structure of the decision by adding an alternative to the existing set of alternatives, then it may happen that the ranks of some previously existing alternatives have been reversed.

Apart from rank reversal, some other aspects of AHP have also received criticisms, such as in the way of asking questions to estimate preference ratios. That is, in comparing the relative importance of distinct attributes, one must ask how much of one attribute (in some specified units) is worth in terms of a particular amount of some other attribute (in some other specified units). Thus, meaningless questions are to be asked in the process and any analysis that fails to address units of measurement when eliciting attribute weights may give very misleading results (Watson and Freeling, 1982). Lockett and Stratford (1987) argued that the ratio type questions are capable of easy misinterpretation, and hence need careful use in practice. For AHP applications with small number of alternatives, pairwise comparisons were used to score the rankings. For large number of alternatives, the number of required comparisons becomes explosive and might result in difficult and awkward questions being asked.

Other criticisms include inconsistent judgements and their effect on aggregating such judgments or on deriving priorities from them. With respect to whether or not the pairwise comparisons axioms are behavioural and spontaneous in nature to provide judgments, Dyer (1990) challenged the validity of the axioms and the principle of hierarchic composition, and provided his own solution considering it consistent with expected utility theory. He added "... each of these axioms has a clear and obvious meaning as a description of choice behaviour. Therefore, each axiom can be debated on the basis of its appeal as a normative descriptor of rationality, and each axiom can also be subjected to empirical testing". This statement is the basis for the criticism of the nine-point scale in the AHP, which has also been criticized by Holder (1991), who also criticised the eigenvector method by questioning the validity of the optics experiment and the principle of hierarchic composition for rank reversal reason.

The principle of hierarchic composition was also criticised by Salo and Hamalainen (1997); Finan and Hurley (2002); Perez et al. (2006); Hurley (2002) and Lootsma (1993). The latter author also criticised the geometric mean in group decision making because it violates Pareto optimality, and attempts to preserve rank from irrelevant alternatives by combining the comparison judgements of a single individual using the geometric mean to derive priorities. In addition, combining the derived priorities on different criteria by using multiplicative weighting synthesis is a criticism of the basic AHP approach.

To overcome these critical issues, many of the foregoing critics have proposed their own remedies as addressed in the literature. In addition to these, the proponents of AHP have also dealt with the above issues, for example, Saaty and Vargas (1984a, 1984c), Harker and Vargas (1990), Vargas (1994), Millet and Saaty (2000). In an attempt to avoid a large number of pairwise comparisons, Liberatore (1987) suggested a methodology of performance ratings method instead of pairwise comparisons in assigning weights to alternatives. Four ratings, namely outstanding, above average, average, and below average were used to rate each alternative against a particular criteria, and pairwise comparisons are required for the four ratings to generate weights for each of the four ratings levels associated with each criterion. This approach differs from that of standard scoring models since the weights provided for the ratings of each subcriterion are not based on arbitrary scales, but utilise a ratio scale for human judgments.

To make validation of several aspects of AHP, Harker and Vargas's (1987) paper is noteworthy. In a most recent book, Saaty (2010) draws the attention of AHP researchers to the outstanding features and critical points of AHP, arguing that rank reversals, which followed some structural changes, were attributed to the use of relative measurement and normalization. Thus, rating alternatives one at a time with respect to the criteria using the ideal mode, always preserves rank because this is equivalent to measuring alternatives one at a time. He points out that all known software programs that people use implement the ideal mode, and when paired comparisons are used, the ideal mode is often used to preserve rank by idealizing only the first set of alternatives but not after. Thereafter, any new alternative is only compared with the ideal and its priority value is allowed to exceed one before weighting, adding and normalizing. This keeps the rank of the existing alternatives always preserved.

According to Tversky et al. (1990), the question is not whether rank should be preserved, because it is widely believed that it cannot and should not always be preserved, but it is whether or not the assumption of independence applies. Saaty (2010) mentions that the fundamental scale of the AHP is theoretically derived and tested by comparing it with numerous other scales on a multiplicity of examples for which the answer was known and hence accepted as a tool for comparing tangible attributes with other intangible attributes.

The simplicity of the hierarchical structure may hide important interdependencies and so oversimplify problems (Roper-Lowe and Sharp, 1990). It also assumes that attributes on the same level are mutually independent and so do not allow for feedback features, such as the impact options might have upon decision criteria. “It is true that an extension of AHP allows the representation of more complicated relationships through the so-called Analytic Network Process. That enhances the expressive power of this MCDA methodology” (Petkov et al., 2007). In ANP, the emphasis is placed on the comprehensiveness of the relationships among the elements of a network rather than the element itself. A brief overview of the method is given below while a detailed discussion is presented in chapter four.

2. The Analytic Network Process (ANP)

The ANP is also developed by Thomas L. Saaty and originally called the supermatrix technique. It is a generalisation of the AHP decision methodology, where hierarchies are replaced by networks enabling the modelling of feedback loops. It is supported by *SuperDecisions* and completed with the interaction and dependence of higher-level elements on lower-level elements and relations in the form of feedback structure that looks like a network. The ANP is a holistic approach (as the opposite of a linear approach) in which all the problem criteria are structured in advance in a network system. The ANP overcomes the traditional OR/MS approaches in the context of Systems Thinking. It is "much broader and deeper than the AHP and can be applied to very sophisticated decisions involving a variety of interactions and dependencies" (Saaty, 2005).

The ANP has been adopted in this research due to its suitability in handling tangible and intangible factors that have bearing on making a decision allowing for interaction, dependency (inner and outer) and feedback within clusters of elements. Such feedback can capture the complex effects of interplay in human society, especially when risk and uncertainty are involved, offering solutions in a complex multicriteria decision environment. Some other features in support of its appropriateness as a dominant methodology in this study include its capability of analysing societal, governmental and corporate decisions creating a comprehensive framework, as it has been applied to a large variety of decisions: technical, marketing, medical, etc. (see Saaty and Ozdemir, 2005; Saaty and Vargas, 2006 and Saaty and Cillo, 2008). As it is based on deriving ratio scale measurements, it provides a way to input judgements and measurements to derive ratio scale priorities for the distribution of influence among the factors and groups of factors in the decision. It is also based on the knowledge and experience of the experts in the field and so relies on the process of eliciting managerial inputs, and allows for a structured communication among decision makers (Saaty, 2005).

Although ANP is built on the widely used AHP, it is more comprehensive than the AHP and especially powerful in decisions involving a variety of interactions and dependencies so that it can act as a qualitative tool for strategic decision-making problems. It is particularly recommended for cases where the most thorough and systematic analysis of influences needs to be made. "It is relatively a new methodology that is still not well-known to the operations research community and practitioners" (Shang et al., 2004). To the best knowledge of the author, no previous application of ANP method to rural telecommunication infrastructure selection is cited in the published literature (Gasiea et al., 2010 and 2009a&b).

In contrast, there are a number of limitations and drawbacks of the ANP. Some of the AHP limitations discussed above are also applicable to the ANP. One of these includes identifying the problem's relevant attributes, determining their relative importance in the decision-making process, which requires extensive consultations, and brainstorming sessions. Hence, data acquisition is a very time intensive process, which calls for a lengthier time to carry out practical implementation.

Moreover, the ANP consists of a plethora of interrelated factors and attributes, so the number of factors and their mutual relationships increase beyond the ability of the decision-maker to comprehend distinct pieces of information. Hence, the complexity increases exponentially with the number of elements and their interdependencies, due both to the substantial number of pairwise comparisons and to the dimensions of questionnaires (Gasiea et al., 2009a). As compared to the AHP, the ANP requires many more calculations and formation of additional pairwise matrices than the AHP and hence it needs a very careful track of pairwise judgements matrices, which are mainly subjective, in which the accuracy of the judgements depends on the experts' knowledge (Saaty and Vargas, 1994).

3.3.5 Applications of the AHP/ANP in telecommunications

Over the past decades the complexity of telecommunication industry decisions has increased rapidly, thus highlighting the importance of developing and implementing sophisticated and efficient quantitative analysis techniques for supporting and aiding such decision making. "Decision support in telecommunications increases the range of its applications. There is no doubt that, with the increasing complexity of telecommunication networks and services, the demand for decision support in this field will also grow" (Granat and Wierzbicki, 2004). MCDM methods are not yet broadly used in telecommunications because its methods are not widely known by researchers working on telecommunication networks. Telecommunication problems that can be examined by such methods can be classified as follows (Granat and Wierzbicki, 2004):

- **Support for strategic management**: it is one of the most important areas because the complexity of the services and infrastructures shifted the importance of the decisions from operational to strategic decisions;

- **Routing**: it is an important problem because the telecommunications networks are actually an infrastructure to provide various services on a different level of quality of service, and therefore, it has became one of the most significant areas of network management;
- **Network planning**: it is a highly complex process, especially within rural settings. However, the application of various analytical modelling and analysis approaches significantly improves the reliability and quality of network plans; and
- **Network design**: it entails the consideration of a more detailed level than network planning, as a designer must choose the technology and has to find various parameters of the network realised in a specific technology.

A summary of published literature on the application of AHP/ANP in telecommunications planning and design, with particular focus on their use in rural telecommunications technology selection is given below.

Douligeris and Pereira (1994) used the AHP for selection of telecommunications network vendors and technologies such as Fibre distributed data interface and distributed queue dual bus that satisfies customer needs in terms of quality of service and decision making between two telecommunications service providers. In the context of a rural areas network planning, Nazem et al. (1994) used the AHP, to develop a two-phased decision support system. It is to aid the design, with the objective to build the best-optimised rural area telecommunications network via hub cities, considering the criteria of population, economy, health, education and transport. In another study, Nazem et al. (1996) used MCDM methods such as compromise programming, in the selection of hub cities for a telecommunications network that spans several rural communities.

Raisinghani and Schakade (1997) studied multicriteria approaches for supporting strategic decisions on e-commerce, based on AHP and ANP. Antunes et al. (1998) tackled strategic telecommunication planning problems, namely regarding the evolution policies towards the deployment of technologies capable of providing broadband services in a residential and small business setting. This model considers the feasible combinations of service categories and technology architectures for the access network. Also, Kim (1998) presented a survey on the evaluation of intranet functions using AHP, in which a hierarchical structure of Intranet functions was built by using the AHP.

Another application of AHP is reported in Tam and Tummala (2001) that employs AHP for the combined selection of telecommunications vendor and system. The authors highlighted the applicability of the AHP and its potential capability to reduce the time taken in the selection process. Sasidhar and Min (2005) used AHP to select optimal high-speed access technology for a rural community under a multiple number of criteria such as cost quality and speed. Nepal (2005) applied the AHP, among other systemic techniques, on the evaluation of rural telecommunications infrastructure in the province of Kwa Zulu Natal, South Africa.

Furthermore, Andrew et al. (2005) presented an AHP model to enhance the selection of more appropriate communication technology solutions in rural areas. They claim that the AHP provides a logical framework that enables an individual or a group of stakeholders to make effective decisions in complex situations by providing a structure in the decision making process. It was stressed that any decision-making related to technology selection serves as an enhancement to human judgement by, amongst other things, managing tyranny of the quantity of conflicting criteria, and the subjectivity of the individual decision-makers towards and acceptable consensus decision.

The same authors stated that the entire AHP modelling session for such a case study was shorter than the traditional processes to reach a consensus choice. They recommended AHP as an elegant and efficient technology selection approach for rural telecommunications that could formalise the judgements of ‘experts’, concerning multiple conflicting criteria, in a structured way towards a consensus and confident choice. They concluded that such a process would be refined with experience, increasing the accuracy of and the time taken to make the most appropriate choice of rural telecommunications technology. Moreover, they envisaged that an AHP decision-making template would be developed for the selection of rural telecommunication technologies that would be regularly updated and improved.

To the best knowledge of the author, applications of the ANP to the selection of rural telecommunications infrastructure technologies have not been tackled (Gasiea et al., 2010). This study therefore aims to fill this gap in the literature to particularly allow for the explicit consideration of dependencies and interactions in the decision making process, and still maintain the acknowledged advantages of the AHP method. The ANP method is considered a suitable approach to understand and analyse problems of this type, in which planners of rural telecommunication services should become sensitive to other factors, apart from the technical aspects such as, economic, sociological, regulatory and environmental issues to adequately address the provision of such services (Daniell, 1992). The methodological framework of ANP is well suited to problems with complex nature of rural telecommunications systems. In order to achieve the aim and objectives of this research, a comprehensive analytical decision structure for the selection of rural telecommunication technologies will gradually be developed.

3.4 The applicability of SSM to rural telecoms infrastructure selection

This section explores the applicability of another existing field, dealing with solving complex problems in organizations, known as Soft Systems Thinking, in particular, Soft Systems Methodology (SSM) to this study, as was mentioned earlier in section 3.2.

Systems thinking, in the form of a general theory, emerged in the 1950s, as a powerful intellectual approach useful for tackling issues that are embedded in complexity, particularly where that includes an application to a wide range of human activity (Demos, 2002). It is a rigorous tool to understand the nature of complexities experienced when deploying telecommunications infrastructure in "messy" rural areas by giving a structure to such complex situations, and allows them to be dealt with in an organised manner. It assists the user to look for a solution that is more than technical and provides a very rational view of the situation.

Soft Systems Methodology (SSM) is one of the systems thinking approaches, which was developed by Checkland in the 1970s as an intellectual discipline and strategy for handling complex problems, including those involving socio-technical systems. SSM is a structured way to establish a 'learning' system for investigating messy problems because it is founded on the paradigm of 'learning' rather than on the paradigm of 'optimization'. A brief account of the SSM stages that are relevant for the purpose of this section is given below, while for further details, one can refer to Checkland and Scholes (1999).

A seven-stage process of analysis describes the original methodology that uses the concept of a human activity system as a means of getting from 'finding out' about a situation to 'taking action' to improve the situation (Checkland and Scholes, 1999). The first and second stages are concerned with finding out what the problem is, summarising it in what are so called a 'rich pictures'. Rich pictures are cartoon-like images expressing the features of the situation and capturing the structure of a problem, the processes involved and the relationships between structure and processes. They are enhanced means for recording relationships and connections than is the case in linear methods (Petkov et al. 2007).

The root definitions describing the new system are formulated in the third stage, by identifying six CATWOE analysis elements (Checkland and Scholes, 1999):

1. Customers: the victims/beneficiaries of the purposeful activity;
2. Actors: those who are involved in the activities;
3. Transformation process: the purposeful activity transforming an input into an output;
4. Weltanschauung: the view of the world that makes the root definition meaningful in context;
5. Owners: who can stop the activity; and
6. Environmental constraints, affecting the situation.

The conceptual models for the future solutions are built in the fourth stage. This is done by pulling out the minimum number of verbs that are necessary to describe the activities that would have to be present to carry out the tasks named in the root definition. These models are compared with reality in the fifth stage. The final stage involves the implementation of changes that are both desirable and feasible.

Nowadays, this formulation of SSM is known as 'mode 1' SSM, while mode 2 SSM was introduced as a two-stream inquiry in 1990: a logic-based stream of analysis and a stream of cultural analysis, including also social system analysis and political system analysis (Checkland and Scholes, 1999). SSM is widely used in practice and it has become a major topic in systems research. However, there have been some criticisms levelled at it. Some of the main criticism points are mentioned below. However, for a thorough evaluation of SSM and in-depth discussion, one can refer to Flood and Jackson (1991) and Jackson (2003).

- The nature of the interpretive theory that characterises SSM constitutes the first criticism. It is argued that problem situations in organizations are not only related to the conflicting worldviews of the individual actors, for which an accommodation is sought in SSM, but are also due to the neglect of cybernetics laws within an organization, which are not taken seriously by SSM;
- The theme of consensus versus conflict represents the next criticism. It is argued that SSM is based on a consensus worldview, which pays little attention to real conflict and coercion. The possibility that individuals or groups may have differences of real interest cannot be conceptualised within the logic of SSM, except through the cultural analysis, which does not fully cater for emancipatory interests;
- In hierarchical settings within an organization, genuine participative debates, on which SSM depends, is severely constrained due to the power imbalances in such organizations. It is quite possible therefore that the results obtained by SSM for a particular problem situation, would favour the powerful, i.e., the position of powerful

stakeholders is not threatened by soft systems studies because significant issues can be kept off the agenda for debate. Although the two-strand version of SSM recognises power, the methodology is not explicit about its neutrality in situations where it is not possible to have unconstrained debate;

- The difficulties encountered in assembling the richest pictures, without imposing a particular structure and solution on the problem situation. Another limitation that can be experienced in SSM is the requirement for participants to adapt to the overall approach and the possibility of narrowing the scope of the investigation too early (Checkland and Scholes, 1999). SSM also criticised for its subjectivism or its idealism, and for its consequent failure to come to terms with structural features of social reality such as conflict and power (Jackson, 1995); and
- In many areas, the SSM cannot be defined by the subjects or issues to which its ideas may be applied requiring a substantial investment of effort, and thought. In addition, the range of interconnections and feedback makes it impossible to predict, in advance, the detailed consequences of interventions. In fact, the consequences are often counter-intuitive (Demos, 2002).

According to Jayaratna (1994), an important deficiency of SSM is the lack of support given by it during the Choice and Implementation stages of Simon's model of decision-making given in section 3.3. Dyer and Forman (1992) argued that the AHP focuses on the choice phase of Simon's model of decision-making. According to Petkov and Petkova (1998), Saaty's definition of the decision making process includes these steps:

1. Structure a problem with a model that shows the problem's key elements and their relationships;
2. Elicit judgments that reflect knowledge, feelings or emotions;
3. Represent those judgements with meaningful numbers;
4. Use these numbers to calculate the priorities of the elements;
5. Synthesise these results to determine an overall outcome; and
6. Analyse sensitivity to changes in judgements.

Petkov and Petkova (1998) pointed out that the above steps seem to be strongly influenced by the characteristic of the AHP. They argued that the results of Arbel and Tong (1982) who applied AHP in a broader context, for the generation of options in decision analysis problems, are relevant for both the Intelligence and the Design phases in Simon's model. They stressed that AHP may support also the Implementation phase of that model through the prioritization of activities/factors involved in a problem, revealing its systemic nature as applicable to all the stages of the decision making process concerning either individuals or groups. The same authors concluded their analysis by stating that AHP could be recognized as relevant to the systems field but is not enough as a single systems methodology, mainly due to the fact that problem structuring phase within it, when compared to Simon's model of decision making, is not formalised. This constitutes AHP's weakest point as it assumes that the problem has been identified and a hierarchy can be designed for it which relies for the definition of the model only on brainstorming. They suggested a complementarist approach involving some of the Problem Structuring Techniques (Rosenhead, 1989) like SODA or SSM in combination with AHP might account better for these two phases.

Generally, both SSM and MCDM approaches can deal with rough problems. The AHP/ANP represents complex problems as hierarchies and networks, respectively. As stated above, SSM's expression of a problem situation is in terms of rich pictures supported by CATWOE analysis and relevant conceptual models. SSM permits techniques such as graphs, texts, animation, pictures, charts, tables, etc. that help to express or capture the essential aspects of a problem situation. The SSM appropriateness for ill-structured or wicked 'messy' problems is acknowledged, as it is more flexible than MCDM methods in representing complexity in problems. In MCDM, one may also comprehensively handle complex multicriteria problems by using BOCR-based ANP in which several hierarchies are used in order to reflect the different sides of the problem such as benefits, opportunities, costs and risks.

SSM is rather interpretive and hence does not claim to be goal-oriented, and organisations are studied with SSM from a hermeneutic stance (Checkland, 1981). AHP/ANP pays special attention to goals and objectives. Besides, in SSM, only qualitative variables are considered, while in AHP/ANP qualitative and quantitative ones can be considered. The incorporation of subjective data in decision problem in AHP/ANP is controlled through the consistency ratio which provides a feedback mechanism for checking the decision makers' judgements. MCDM in general, and AHP/ANP in particular, also allow the incorporation of uncertainty in the decision making process through interval judgements and fuzzy logic. These latter features are not available in SSM.

With respect to the role of goals, granularity of the problem components and the structuredness of the problems suitable for a particular technique, SSM allows different granularities in the decomposition of the problem at different levels of system description, but it seems that within a particular level of a model, the granularity is the same. AHP/ANP allows different granularities at different levels in the same model. Moving down the hierarchy, one can capture finer aspects of the model. As briefly explained in section 3.3.4, hierarchies are only special cases of more general network models that can capture the interdependencies among elements within the structure. The expressive power of ANP, which is an extension of the AHP, allows for the representation of more complicated relationships, making it much more powerful than the AHP.

"The number of links in a system that can be represented and measured in a network model is far greater than what is possible in SSM models" (Petkov and Petkova, 1998). In ANP, the range of interconnections and feedbacks among the intangible factors is predictable, while, in SSM, the range of such relations makes it impossible to predict, in advance, the detailed consequences of interventions that are often counter-intuitive (Demos, 2002). In addition, unlike SSM based analysis, which sometimes lacks a sense of direction in the endless sequence of iterations on a particular problem, the capability of MCDM methods, in particular, the ANP, of enabling analytical evaluation of both qualitative and quantitative variables under several conflicting criteria is impressive. For instance, in terms of the inclusion and expression of strength (measurement) of the multidimensionality of the tangible and intangibles factors involved, the AHP/ANP applies the fundamental measurement scale, in which one chooses whether to use a relative, ideal or absolute measurement level (see subsection 3.3.3). In contrast, SSM does not provide a means for measuring the intensities of relationships between elements of a problem, which in this case is the selection of rural telecommunications infrastructure.

In conclusion, the above discussion, reasons and pitfalls levelled at SSM add substantial complexities to the problem at hand making the SSM inapplicable to the selection of rural technologies situation. The salient features of the ANP described in chapter 4, allow it to be applied on its own as a substitute for AHP and also for SSM in the selection of rural telecommunications in which the action and the result has an affect on the stakeholders.

3.5 The conceptual model

A rural telecommunication system is characterised by complexity and non-linearity. Therefore, the selection of rural telecommunications technology cannot be fully performed without understanding the interactions and relationships among the different factors. Therefore, it becomes clear that when providing rural telecommunication services, the focus is on non-linear relationships rather than linear ones (Begun, 1994).

Figure 3.1 fairly represents the general practice in the planning of telecommunications technologies. In view of the network planning, functions and interfaces illustrated in the Figure 3.1, one observes a systematic functionalist approach, in which only certain parts of the model depicted in Figure 3.2 are considered. However, in developing countries, the selection of rural telecommunications infrastructure is characterised by complexity and non-linearity compounded by the absence of past statistical data to analyse, such as technical, economic, etc. This calls for a powerful method that relies on experts' opinions and is capable of incorporating both tangible and tangible factors.

The analysis and synthesis by a group of experts rather than an individual in rural settings allow telecoms planners to identify, assess and understand the interactions and relationships among the different diversified factors, so that proper decisions can be reached. Thus, in considering the issues pertaining to rural telecommunications presented in chapter two and based on the ANP theory covered in chapter four, a typical conceptual model for the selection of rural telecommunication technology should be conceived as illustrated in Figure 3.2.

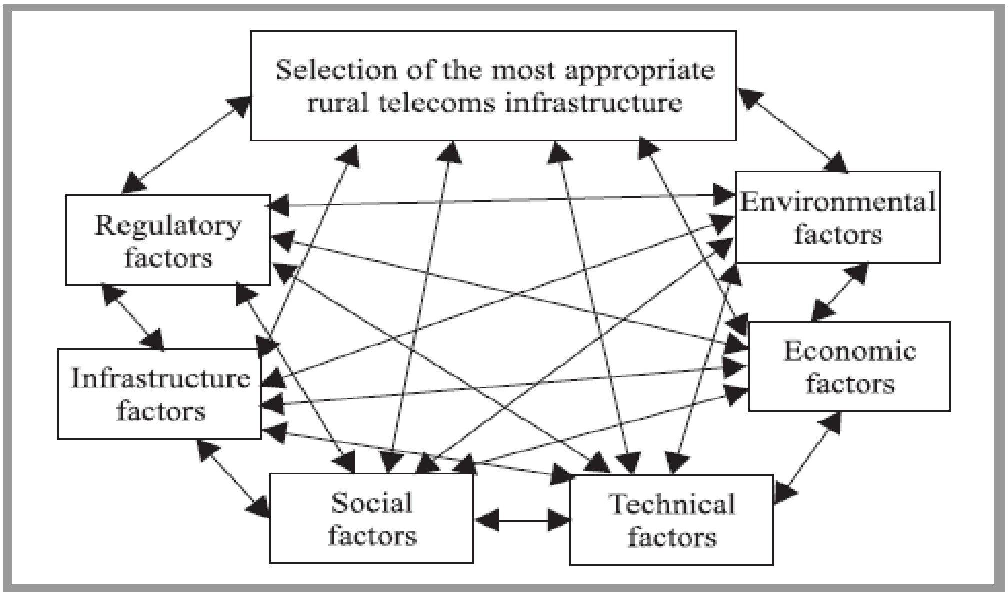

Figure 3.2 A conceptual model for the selection of rural telecoms technology

The conceptual model illustrated in the figure above approximates the real situation meant only for the purposes of gaining a deeper understanding of the problem and to justify the adopted multicriteria approach. The model considers the possible synergy among several diversified factors by representing the selection process evolving as a result of the interdependent relationships among the factors (the figure does not reflect all possible factors). This conception clearly indicates that such a selection process is interdependent on factors, which are themselves interdependent on each other, and which may be regarded as groups having subgroups of their own.

The obvious significant implication of this model is the fact that the technical factors are only one subset among others when selecting rural telecommunication technologies, albeit a necessary part. The other factors depicted in the figure, such as the sociological, environmental, economic, regulatory and infrastructure, are regarded as essential factors that also need to be considered and examined more closely in the process. This can be envisaged as a holistic approach in which the outcome is not only dependent on the technical factors, but arises out of the interactions among the various factors. The ANP supports requisite holism without talking the systems theory language (Cancer and Mulej 2006b) and hence, it was chosen to model such a problem.

3.6 Research methodology

This section presents the research philosophy, approach, strategy and design, and methods used to address the research methodology outlined in chapter 1. The way the research is conducted is generally conceived mainly in terms of research philosophy, research approaches, strategies chosen and different tools and techniques used to achieve the research objectives.

According to Checkland and Holwell (1998), any piece of research is generally based on a simple model of the elements shown in Figure 3.3. The essential elements of this model include an intellectual framework of linked ideas (F), that is a theory in which knowledge about the problem situation or area of concern (A) being researched is expressed. This framework is embodied in a methodology (M) that promotes the use of various research methods and techniques deemed appropriate to the framework for investigating the area of application, that is the research questions.

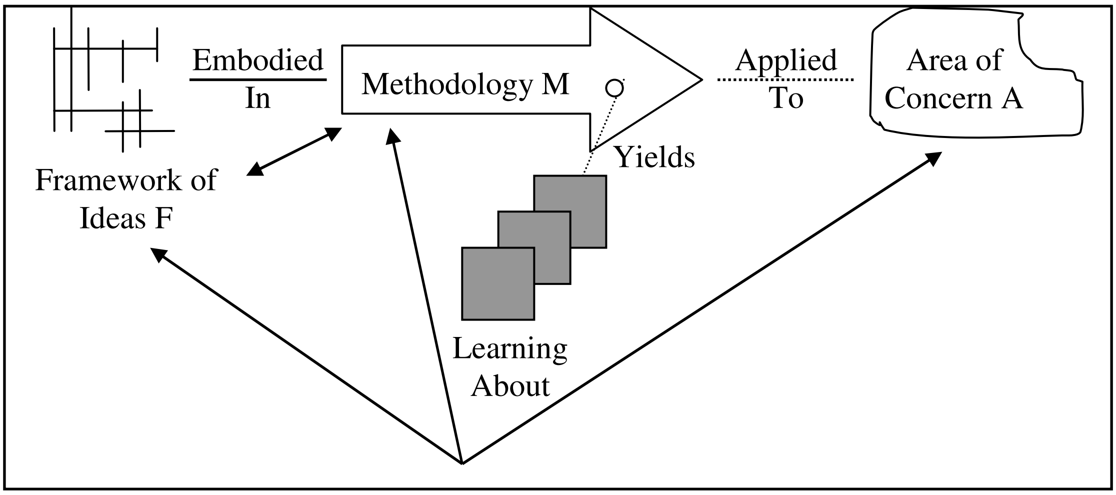

Figure 3.3 Elements relevant to any piece of research (Checkland and Holwell, 1998)

Landry and Banville (1992) clarify the relationships of the whole research process as captured in the research triad depicted in Figure 3.4 (adapted from Landry and Banville (1992) and Robey (1996)). The figure presents a suitable triad for the justification of research in which the rational process for any research is informed by the relationship among the research aim, the theoretical foundation and the research methods. The research aim, in addition to determining the theoretical foundation, also determines the research methods.

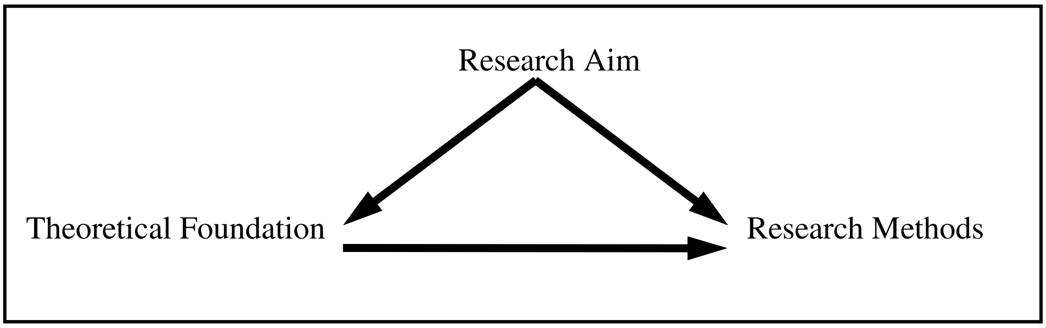

Figure 3.4 A triad for the justification of research (Landry and Banville, 1992)

In this study, the research aim is to provide a comprehensive examination regarding rural telecommunications infrastructure selection by conducting an analytical decision analysis within the context of developing countries. This aim determines both the theoretical foundation, which is very important for revealing the basic features of the research, and the methods that are determined by the theoretical foundation as well (Landry and Banville, 1992; Robey, 1996). The theoretical foundation of the work is what distinguishes research from the realm of theoretically unfounded management consultancy (Jackson, 1995).

The subject of this thesis includes key words ‘telecommunications infrastructure’, however, this research is not confined to the traditional discipline of telecommunications engineering or the traditional technology selection, which is based on experimental ideal of research. During this research, it became clear that the selection of telecommunication infrastructure in rural areas is a complex activity, involving various stakeholders with views that do not necessarily match. Due to the nature of disparities in rural development in most developing countries, the underlying philosophy for the research needs to consider the interests of the stakeholders in such a technology selection process, which cuts across various disciplines.

In addition, this research acknowledges the multiplicity of interrelationships among the diversified factors that affect the selection of technology in rural settings. The complexity of the problem situation leads to the need to explore the applicability of existing methods for solving complex problems like multiple criteria decision making. The addition of the multicriteria approach to the selection process meant that the research methodological approach had to cater for such diversity. Hence, the structure has to include multiple perspectives of decision makers and, for this reason, it was defined within the multicriteria domain. The analysis of this field and its potential applicability is presented in this chapter.

Gibbons et al. (1994) refer to the traditional positivist hypothesis testing research, in which the research bias is towards the framework of ideas (F) shown in Figure 3.3 as Mode 1. Mode 2 research on which this thesis is based is ruled by the area of concern (A) rather than the framework of ideas (F). Jackson (2000) elaborates on Mode 2 research by describing the research process that Mode 2 knowledge has to produce to satisfy the demands of particular users. He argues that research is organised around a particular area of concern (A) and is generated in discussion with those who will find the end result useful. He states that since the research revolves around a real world (A), it is unlikely that any single discipline will be able to provide a suitable (F). He further states that Mode 2 research is ‘transdisciplinary’ in nature and must be flexible in order to respond to the changing and transitory nature of the problem it addresses. Because the issues of real concern are tackled, Mode 2 researchers are more accountable to the public and the quality of the research is judged on a wider set of criteria than just the contribution to the development of a particular discipline.

The area of concern, the selection of rural telecommunication infrastructure for the benefit of all stakeholders, falls within the telecommunications field. However, knowledge from other disciplines such as operations research, multicriteria decision making, analytical decision processes, rural development and planning were essential in achieving the objective of the research and hence necessities a transdisciplinary approach. The general research approach adopted in this study is therefore qualitative in nature.

A qualitative research is more subjective involving examining and reflecting on the less tangible aspects of a research subject, e.g. values, attitudes, perceptions and its methods are designed to help researchers understand people and the social and cultural contexts within which they live (Myers, 1997). It is often adopted when it is required to uncover a person's experience or behaviour, to create a detailed analysis of a particular process of a single case study or limited number of cases and to understand a phenomenon about which little is known (Ghauri and Gronhaug, 2001). Qualitative data sources include interviews, questionnaires and surveys (open-ended), documents and texts, observations (field work), focus groups and researcher's impressions and reactions to understand and explain the social phenomenon (Yin, 2003).

In general, qualitative research may be guided by positivist, interpretivist or critical epistemology. The two fundamental requirements of a positivist research approach (usually followed in engineering), objectivity (observations independent of the observer) and experimental control were not suited to the problem situation at hand, which required more than a deep understanding of every aspect of telecommunications infrastructure selection. It can be stated that the general orientation and the underlying philosophical assumptions of this research followed an interpretivist approach in the sense that the focus was on the improvement of the selection process of rural telecommunication infrastructure. The key purpose of this improvement for the process represents an improvement on current technology selection practice in rural telecommunications, which is seen to be the creation of the preconditions for improvement in rural development.

Based on the above, two activities were used as means to generate the necessary information. These include interactions with many scholars interested in rural telecommunications and intensive literature survey. The latter was conducted in several directions including the following aspects:

- The current planning approaches of rural telecommunication infrastructure;
- The various issues, factors and players involved in the choice of rural telecommunication technologies; and
- The current status of MCDM field, in particular the AHP/ANP methods and their potential applicability to model the technology selection process.

On the basis of the literature analysis on rural telecommunications selection, the need for a multicriteria approach to the problem was indicated. Hence, a framework of ideas (F) was gradually developed in continuous consultation with telecommunication experts around the world. The overall justification of the generic model as a holistic approach to the selection of rural telecoms infrastructure was done from the perspective of the body of knowledge within technological infrastructure selection and multicriteria decision making approaches. In moving towards the research aim, a comprehensive study of the various MCDM approaches and their underlying theory was conducted. A MCDM approach is used to provide a suitable theoretical and philosophical foundation for the development of generic decision models. The ANP was chosen as the overall approach and the dominant methodology for the development of the generic model and the comprehensive framework (using BOCR) because the nature of the problem necessitated the need for multiple perspectives of decision makers and stakeholders that takes into consideration the need for improvement of rural telecommunications infrastructure selection. These approaches could be referred to as the methodology (M) in Figure 3.3.

The ANP method incorporates both qualitative and quantitative approaches to a decision problem. The qualitative part includes: identification of the decision problem; ensuring the suitability of the ANP to solve the problem; decomposing the unstructured problem to a set of manageable and measurable levels; and compiling a list of experts to provide judgments for making the decision. On the other hand, the quantitative part include: designing a questionnaire to collect input data through pairwise comparisons; estimating the relative importance between any two elements in each matrix and calculating the relevant eigenvectors; measuring the inconsistency of each matrix by employing the consistency ratio; and eventually constructing the supermatrix using the eigenvectors of the individual matrices. The research evolution followed in the development of such a generic ANP decision model is depicted in Figure 3.5.

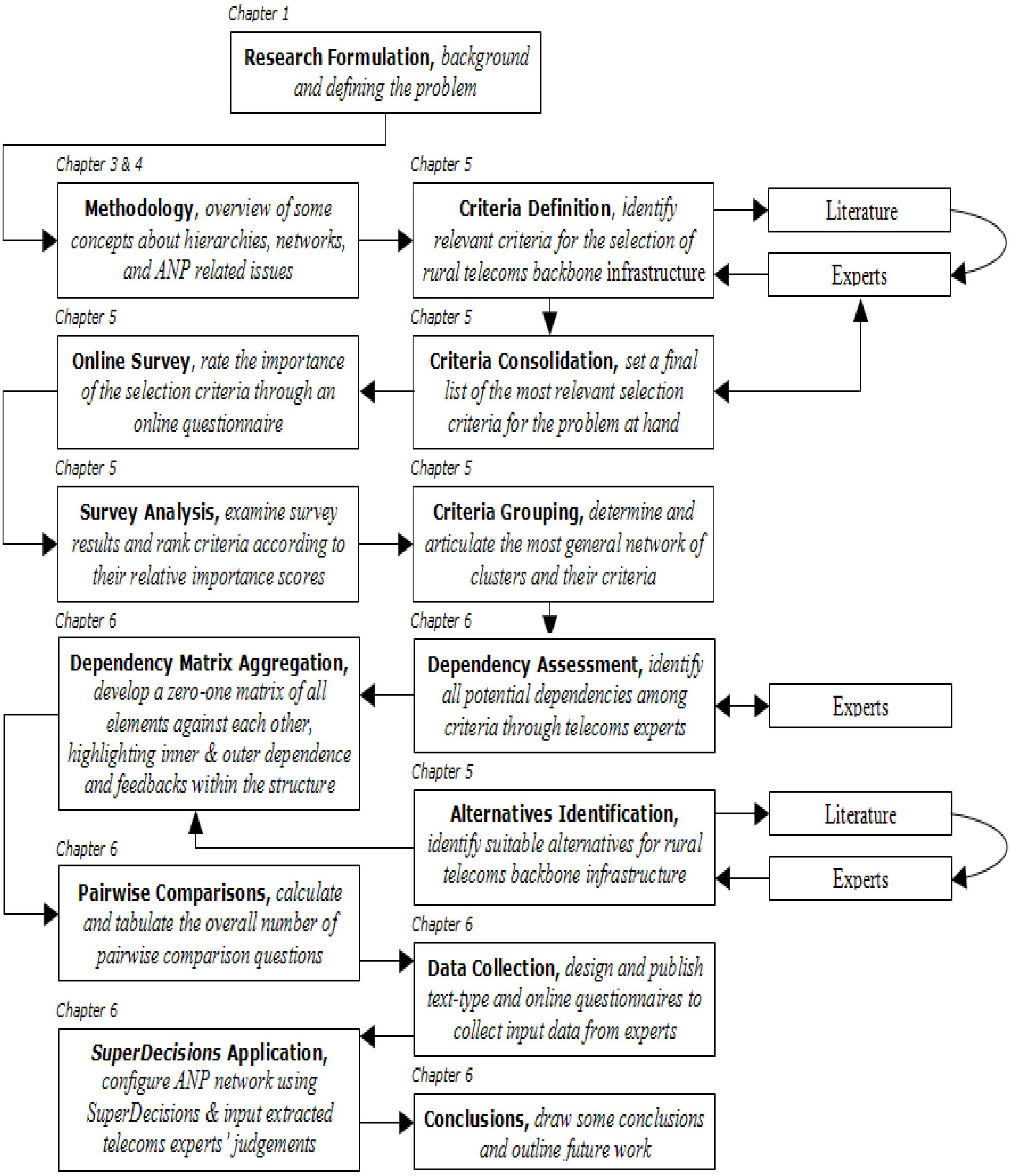

Figure 3.5 The research followed in the development of the ANP model

The next phase involves testing the generic ANP model in a real situation, which necessitates a case study approach, as this research focused on having a better understanding of rural technology selection processes with the intention of enhancing their current practices. According to Yin (2003), a case study research strategy is used in many situations to contribute to our knowledge of individual, group, organizational, social, political, and related phenomena. He argues that a single-case study is similar to a single experiment, and many of the same conditions that justify a single experiment also justify it. He justified using a single-case study with the following five reasons:

1. When it represents the critical case in testing a well-formulated theory;
2. When the case represents an extreme case or a unique case;
3. When the case is the representative or typical case; the objective is to capture the circumstances and conditions of an everyday or commonplace situation;
4. When the case is revelatory; an investigator has an opportunity to observe and analyse a phenomenon previously inaccessible to scientific investigation; and
5. When the case is longitudinal; studying the same single case at two or more different points in time.

In this phase, Libya's main telecoms provider was selected as a case study to describe the practical implementation of the generic ANP decision model for the selection of telecoms technology for Al Qatrun area, which has a typical geographic and demographic profile that makes the selection process within it a challenging exercise. The case study took a great deal of time for planning, arrangements, actual research, interviewing officials and experts and thinking to complete. It entailed a number of meetings with selected telecoms planners who are usually involved in actual projects related to technology selection in rural areas. It eventually involved a workshop that enabled enhanced telecoms planners' participation, and created close continuous interaction with the author who acted as a facilitator.

3.7 Conclusion

Decision making for multiple criteria problems related to telecommunications networks takes place in an increasingly complex and turbulent environment characterised by a fast pace of technological evolution. The complexity of such problem leads to the need to explore the applicability of methods for solving complex problems such as systems thinking and MCDM. The latter approach is adopted in this study.

In this chapter, current practices on the part of telecommunications infrastructure providers were discussed. It was found that research in the area of telecommunications, in particular rural telecommunications planning practice, traditionally has and still focuses mainly on the technological engineering aspects. The ITU for example, recommends four models for rural areas based on settlement patterns and physical geographical layout of the area. Sets of appropriate technologies, including network configurations, are then matched to these four models. While these models refer to the various issues that need to be considered in the selection of rural telecommunications infrastructure, they still do not provide a methodological "technology selection" approach that is suitable to rural and remote areas.

At best, they just call for some form of planning that goes beyond the traditional technology-only aspects.

The ITU also recommended PLANITU software as a planning tool for the optimisation and dimensioning of telecommunications networks. However, the focus is on network planning which is not the same as planning and design of telecommunications infrastructure. The complex issues pertaining to rural areas such as those discussed earlier in chapter two are not given sufficient attention. It is therefore concluded that the planning process that is implied in PLANITU is linear, lacking a comprehensive investigation of the problem situation with respect to rural telecommunications planning for a particular rural area. The rural telecoms infrastructure selection process according to the current rural planning processes and procedures recommended by the ITU, discussed above, was treated as pure technological.

The past research related to planning of rural telecommunications infrastructure was also reviewed. It was noted that some of the reviewed literature falls within the developmental and integrated domain to rural telecommunication and hence provides no enabling planning methodology, model or framework that can enhance such a technology selection process. Others attempts apply some systems thinking methodologies, such as Soft Systems Methodologies (SSM) for the planning task. It was concluded that the traditional approaches and past research cited in the literature in relation to rural telecommunications reveal that the existing approaches, apart from the systems thinking, do not address the problem of rural telecommunications infrastructure selection holistically and are inadequate to represent the selection process.

The most general and widely recognised model of decision making process proposed by Simon (1977) was introduced. An overview of the MCDM methods together with their salient aspects and their classifications and comparisons were also presented. Based on the analysis of the challenges involved in rural telecommunications presented in chapter two, as well as the involvement of several various stakeholders and multiple criteria in the selection of rural telecommunications infrastructure, a concise picture of the issues and relationships amongst these issues related to rural telecommunications was established. The need for a MCDM, in particular the ANP, to the selection of rural telecommunication infrastructure has also been established in this chapter. A literature review in which several group decision-making methods were compared for effectiveness in terms of a set of criteria was conducted. A summary of the results indicated that the AHP and, in particular, the ANP models, demonstrate remarkable performances compared with other methods with respect to almost all adopted criteria.

In conclusion, a MCDM was identified as a suitable approach to understand and analyse problems of this type. Its methodological framework is concerned with understanding complexity in a system and hence suits such complex nature of rural telecommunications systems. In particular, the ANP technique was considered as an applicable potential method, to be used as a dominant methodology to fulfil the purpose of this research. The support offered by ANP for group decision making by providing a mechanism for preserving that anonymity and the *SuperDecisions* software established it as a powerful tool for consolidating opinions in complex situations that usually involve a number of stakeholders.

A literature survey was also conducted to examine a number of weaknesses of AHP/ANP that includes some aspects which have caused emergence of substantial criticisms from many papers identified from the literature. Several types of criticisms are addressed and discussed in this chapter, focusing mainly on the major issues such as the rank reversal problem, the way of asking pairwise questions, inconsistent judgements, the fundamental scale, the eigenvector method, the geometric mean in group decision making, the complexity in ANP which increases exponentially with the number of elements and their interdependencies, etc. It was also mentioned that in order to overcome these critical issues, many of the foregoing critics have proposed their own remedies as addressed in the literature.

This chapter also presented previous attempts to apply AHP/ANP in telecommunication planning and design that were reported in the literature, focusing on their use in rural telecommunication technology selection. While the use of AHP was cited by Andrew et al., (2005) to tackle a rural communication technology selection problem, it was found that applications of the ANP to the selection of rural telecommunications infrastructure have not been reported. The applicability of another existing field, dealing with solving complex problems in organizations, known as Soft Systems Thinking, in particular, Soft Systems Methodology was also investigated. The seven-stage process of analysis describing the original methodology including the six CATWOE analysis elements was introduced. While the SSM is widely used in practice and has become a major topic in systems research, some criticisms that have been levelled against it were discussed in the chapter. It was concluded that the SSM is inapplicable to the selection of rural technologies situation because of those pitfalls that add substantial complexities to the problem at hand. A conceptual model was proposed next to portray the real situation of how one can appropriately select the right rural technology. It is meant only for the purposes of gaining a deeper understanding of the problem and also to justify the adopted multicriteria approach.

Finally, to address the research methodology outlined in section 1.6 in chapter 1, the research philosophy, approach, strategy and design and methods were discussed. Following Checkland and Holwell (1998), a simple model of elements in which any piece of research is generally based was discussed and adopted in this study. The relationships of the whole research process were clarified following Landry and Banville's (1992) research triad in which the research aim determines both the theoretical foundation, which is very important for revealing the basic features of the research, and the methods that are determined by the theoretical foundation as well.

It was stressed that this research acknowledges the multiplicity of interrelationships among the diversified factors that affect the selection of technology in rural settings. The addition of the multicriteria approach to the selection process meant that the research methodological approach had to cater for such diversity, and hence knowledge from other disciplines was essential and hence necessities a transdisciplinary approach. To have a better understanding of rural technology selection processes, with the intention of enhancing their current practices, the application of the generic ANP model in a real situation necessitates a case study research strategy, which is used in many situations to contribute to our knowledge of individual, group, organizational, social, political, and related phenomena.

4. THE ANALYTIC HIERARCHY/NETWORK PROCESSES

4.1 Introduction

Multi-criteria decision-making processes with the AHP/ANP approaches can be utilised to examine hierarchy and network model representations. Such analytical decision processes are fundamentally a way to measure intangible factors. By using pairwise comparisons with judgements that represent the dominance of one element over another with respect to a common property, both methods are capable of possessing qualitative and quantitative elements (Saaty, 2005).

This research investigates the application of AHP/ANP in rural telecommunications infrastructure selection. Preceding chapters have concentrated on rural telecommunications and multicriteria decision making in general, thus, this chapter will mainly focus the discussion on the basic concepts of the AHP/ANP methods, which have found useful applications in decision making that involves numerous intangibles.

This chapter begins by briefly highlighting the differences between hierarchies and networks. The AHP theory covers the principles, axioms upon which the AHP/ANP is based and the methodology. All aspects of the AHP methodology including the structuring of the decision problem, pairwise comparisons, determination of normalised weights and synthesis are discussed in detail in this chapter. Two computational algorithms for estimating the local priority vectors, namely the eigenvector method and the geometric mean method are introduced. A discussion of the measure of consistency, which is used to check a set of judgments in a pairwise comparison matrix, known as 'consistency ratio' is also given.

In a further section, the dominant methodology adopted for this research is introduced. The focus is more on the aspects that characterise the ANP from the AHP, such as the construction of the network model, supermatrix formation and transformation and synthesis. Sensitivity analysis, which tests the stability of the outcome to wide perturbations in the judgements, is discussed followed by an account on the BOCR-based ANP method. A comparison of the AHP/ANP methods outlining their advantages and disadvantages is presented, then an introduction to group decision making is given. This is to firstly show how to aggregate individual judgements and secondly how to construct a group choice from individual choices by aggregating individual judgements. The chapter sums up by presenting some concluding points.

4.2 The nature of hierarchies and networks

A hierarchy is a system where one group of entities influences another set of entities in another level of the hierarchy. It decomposes from the general to the more specific attributes until a manageable level of decision criteria is reached. According to Saaty and Vargas (1994), a hierarchy is a particular type of system, which is based on the assumption that the elements influencing the decision problem can be grouped into disjoint sets. The elements of one group (level) influence only the elements of one other group, and are themselves affected by the elements of only one other group. The elements in each hierarchical level are assumed independent (Saaty and Vargas, 1994). These authors observed that the main aim of a hierarchy is to understand the goal (the highest level in a hierarchy) based on the interactions of the various levels, rather than directly from the elements of the levels.

The hierarchy illustrated in Figure 4.1 is a linear top down structure that has a goal (problem definition) at the top level to model the decision problem. The subsequent levels model the criteria, subcriteria and alternatives. The clusters at each level are special networks that do not have inner dependence and no feedback from lower to higher levels. The arc from a cluster at a higher level to a cluster at a lower level indicates the influence of the criteria in the lower level cluster (affecting elements) on a criterion in the higher level cluster (affected element). A loop at the bottom level shows that each alternative in that level only depends on itself and thus the elements are considered independent from each other (Saaty, 2005).

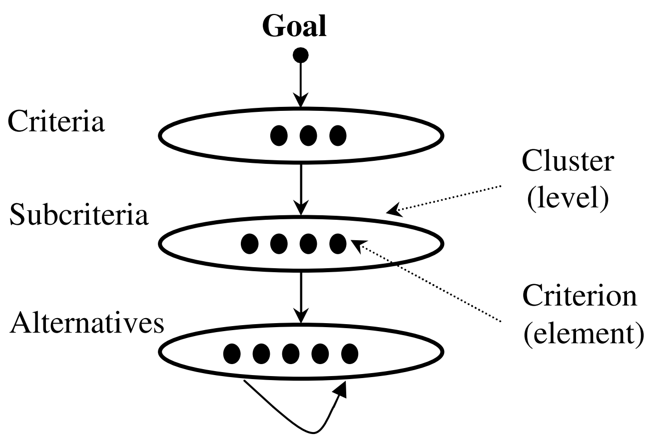

Figure 4.1 A linear hierarchy

Unlike a hierarchy, a network has a non-linear structure, which spreads out in all directions. It consists of clusters (components) that include elements in them, which correspond to levels in a hierarchy, and are not arranged in any particular order. It introduces a free form of ordering elements, in contrast to a predetermined importance chain as in a hierarchy. It can be used to identify relationships among clusters using one's own thoughts, and is especially suited for modelling dependence relations.

Such a network approach makes it possible to represent and analyse interactions and to synthesize their mutual effects by a single logical procedure (Saaty, 2005).

A network can be generated from a hierarchy through gradual increase of a number of hierarchical connections. Its need emerged from the fact that many decision problems cannot be represented hierarchically, as to allow for the interdependencies and influences of a higher-level elements upon a lower level elements within the hierarchy. It always contains the alternatives of the decision along with clusters of criteria of different kinds of influences and particularly those that influence the alternatives directly. In its structure, there are two kinds of influences, namely outer and inner dependencies (Saaty, 2005).

1. Outer dependence: In which one compares the influence of elements in a cluster on elements in another cluster with respect to a control criterion. The influence is transmitted from a cluster to another one and back, either directly from the second cluster, or by transiting through intermediate clusters along a path, which sometimes can return to the original cluster forming a cycle. In figure 4.2, arrows pointing from clusters indicate that those clusters influence the clusters to which they point. Appropriate lines show influences between clusters with arrows from one cluster to another to indicate outer dependence. For example, the arc from cluster C1 to C3 indicates the outer dependence of the criteria in cluster C3 on the criteria in cluster C1 with respect to a common criterion.

Whenever feedbacks exist in a network structure, it means there are mutual outer dependencies of criteria in two different clusters, as can be seen between clusters C3 and C4. The alternatives' cluster of a network may or may not have feedback to other clusters. Feedback structure - mutual outer dependence of elements in two different clusters - does not have the linear top-to-bottom form of a hierarchy but looks more like a network. With feedback, the alternatives can depend on the criteria as in a hierarchy but may also depend on each other. The criteria themselves can depend on the alternatives and on each other as well. For instance, one may compare the alternatives with respect to criteria, and also compares the dominance of one criterion versus another for each alternative. This is actually the strength of the ANP approach because dependence and feedback are incorporated in real life problems, in which a decision process not only compares alternatives with respect to criteria as in the AHP but also considers the alternatives' specifications.

Moreover, feedback loops of influence between both elements and components can cause an unimportant element to become important. Because it is possible for an element, which has low priority in its component but has high priority of influence on elements in other components to obtain a high overall priority in the limit supermatrix. This shows that while in a hierarchy one can proceed downward by ignoring the judgments of subcriteria and alternatives under a low priority criterion, one cannot do the same in a feedback process because an initially unimportant criterion may become more important in the cycling and limit operations (Saaty, 2010).

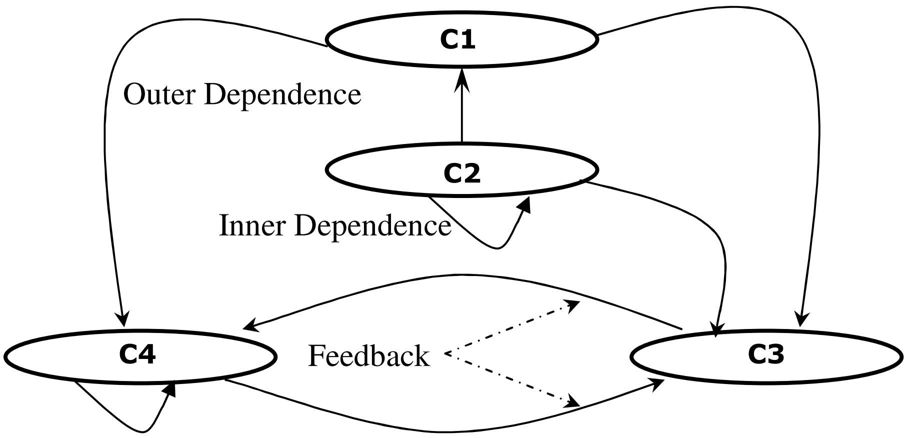

Figure 4.2 A non linear network

2. Inner dependence: In which one compares the influence of elements in a group on each other. For example, a loop in a cluster such as C2 or C4 in figure 4.2 indicates inner dependence of the criteria in that cluster with respect to a common criterion. Also, from Figure 4.3 below, clusters C2, C4 and C5 have loops that connect them to themselves indicating inner dependence.

Figure 4.3 also illustrates three types of clusters in a network and their connections: Source, Sink and Intermediate. C1 is a source cluster because no arrows feed into it, i.e. C1 has an effect on C2 but C2 does not affect C1; C5 is a sink cluster (absorbing state) with no arrows leaving it. An intermediate cluster C2 (transient state) has arrows feeding into and leaving it, while intermediate clusters (recurrent state) C3 and C4, fall on a cycle because they feed back and forth into each other. The network connecting the clusters of a decision problem must always be connected and cannot be divided into two or more disconnected parts. Otherwise, they cannot communicate with each other and so asking for the influence of one part on another becomes pointless because there can never be any (Saaty, 2010).

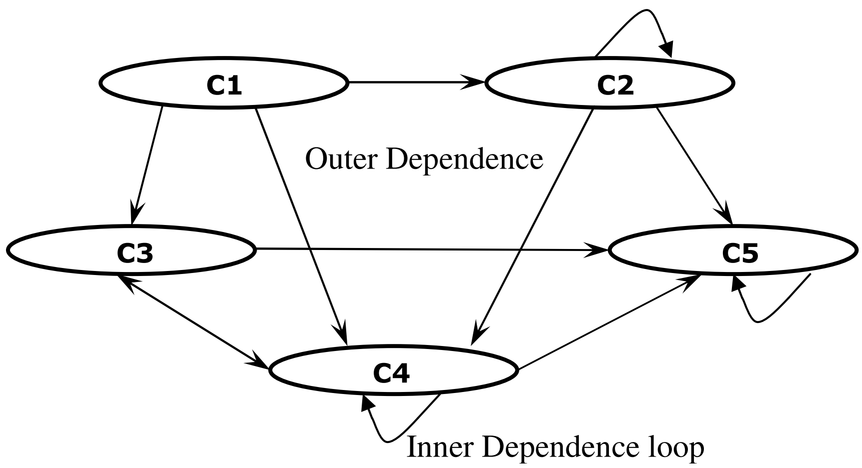

Figure 4.3 Connections in a network structure

Feedback structure - mutual outer dependence of elements in two different clusters - does not have the linear top-to-bottom form of a hierarchy but looks more like a network. With feedback, the alternatives can depend on the criteria as in a hierarchy but may also depend on each other. The criteria themselves can depend on the alternatives and on each other as well. For instance, one may compare the alternatives with respect to criteria, and also compare the dominance of one criterion versus another for each alternative. This is actually the strength of the ANP approach because dependence and feedback are incorporated in real life problems, in which a decision process not only compares alternatives with respect to criteria as in the AHP but also considers the alternatives' specifications.

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The following section will discuss various aspects related to the AHP method.

4.3 The analytic hierarchy process

The AHP was developed by Thomas Saaty who started working on its development in the early 70s. It is a multi-criteria decision making method which decomposes a complex problem into a hierarchy consisting of specific elements. It is an effective tool that can handle both tangible and intangible attributes, especially when dealing with multifaceted problems. Due to the wide applicability, ease of use and implementation of the AHP, it has been studied extensively and has been used in diverse areas for solving complex decision problems. In addition, the use of pairwise comparisons that are based on the judgements of knowledgeable experts to compare alternatives, allows the decision maker to focus on the comparison of just two objects, making the observation almost free from irrelevant influences.

The AHP can be adapted easily where decision making is performed by a group rather than an individual. Roper-Lowe and Sharp (1990) found that structuring a problem as a hierarchy is a useful aid to understanding problems and driving discussion about them. This process can reveal issues which have not previously been explicitly stated. In addition, the process is easy to understand and the decision makers are comfortable with it. It is applied in four steps (Saaty, 1980): (1) Constructing a hierarchy describing the problem. (2) Constructing matrices for pairwise comparisons between successive levels. (3) Producing priorities, or relative weights, of the elements at each level of the hierarchy using eigenvectors. (4) Synthesising the relative weights of the various levels obtained from the third step in order to produce an overall score of decision alternatives. All these steps will be discussed in some detail in subsection 4.3.2.

The AHP is designed so that during the decision making process, judgements are made using simple pairwise comparisons and then used to develop overall priorities for ranking the alternatives. Since the comparisons are to be carried out through personal or subjective judgements, some degree of inconsistency is to be expected. To guarantee the consistency of the judgements, an operation called consistency verification, which is regarded as one of the key advantages of the AHP, is incorporated in order to measure the degree of consistency among the pairwise comparisons by computing the consistency ratio. If it is found that the consistency ratio exceeds the limit, the decision makers will be asked to review and revise the pairwise comparisons (Ho, 2008). The AHP therefore allows for inconsistency in the judgements and provides a means to improve consistency. An account of how to compute the consistency ratio will be discussed in a later subsection.

The AHP is a flexible method for formulating and analysing decisions. It is used to aid and shorten the decision process through generating insights but not to replace it. The three major concepts behind the AHP are: analytic, hierarchy and the process (Harker, 1989). Analytic is the process of using numbers to represent priorities. In holistic decision situations, decisions are arrived at by "guess" and no numbers are involved. The use of mathematics can help to describe one's choice to others. Hierarchy is the procedure of breaking and structuring the decision problem into levels, including goals, criteria, subcriteria and alternatives. The decision maker can then focus on smaller sets of elements which is effective when dealing with complex situations. Process is a significant element in decision making, which involves learning, debating and revising one's priorities.

4.3.1 AHP principles and axioms

The AHP is based on three principles in problem solving including decomposition or hierarchic design, comparative judgement and synthesis of priorities or hierarchic composition. The decomposition or hierarchic design principles entails structuring a decision problem into a hierarchy. The hierarchy comprised of at least three levels, starting from the goal at the top level to criteria bearing on the goal in the second level, followed by subcriteria in the third level, and so on. Alternatives are at the bottom level where the choice is to be made (Saaty, 1986).

The principle of comparative judgement involved setting up a matrix to carry out pairwise comparisons of the relative importance of the criteria at each level with respect to a given criterion at the next higher level. A fundamental scale of measurement is defined to enter judgement in pairwise comparison. The comparison matrices are applied from the second level of the hierarchy down to the bottom level and the entries are used to generate a derived ratio scale, which are necessary to establish measurements for intangible properties using numerical judgments from an absolute scale of numbers. Such measurements, when used to represent comparisons can be related and combined to define a cardinal scale of absolute numbers that are necessary to use when intangible factors need to be added and multiplied among themselves and with tangible factors. The final step is to apply the synthesis of priorities principle (Saaty, 1980).

In order to synthesise the priorities, one can multiply the local priorities from the second level by the priority of their related criterion in the level above and adding them for each element in a level according to the criteria it influences. The global priority of that element is thus obtained, which is then used to weigh the local priorities of elements in the level below compared by it as criterion, and so on to the bottom level. An intrinsic measure of inconsistency for each matrix and for the whole hierarchy can be implemented. This measure serves to determine those judgements which require re-evaluation. The three principles of AHP are supported by four axioms concerned with the reciprocal relation, comparison of homogenous elements, hierarchic and systems dependence, and expectations about the validity of the rank and value of the outcome and their dependence on the structure used and its extension (Saaty, 2001).

Axiom 1 ***(Reciprocal)***: The decision maker must be able to make comparisons and state the strength of his preferences. The intensity of these preferences must satisfy the reciprocal condition: if A is x times more preferred than B, then B is $1/ x$ times more preferred than A. This axiom specifies the reciprocal condition in pairwise comparison. Whenever such comparisons are made, it is necessary to consider both members of the pair to judge the relative value. The smaller or lesser one is first identified and used as the first unit for the criterion in question. If, for example, one stone is judged to be five times heavier than another, then the other is automatically one fifth as heavy as the first. The comparison matrices are formed by making paired reciprocal comparisons. This simple but powerful means of resolving multicriteria problems is the basis of the AHP (Saaty, 2010).

Axiom 2 ***(Homogeneity)***: The preferences are represented by means of a bounded scale. "Homogeneity is essential for comparing similar things, as the human mind tends to make large errors in comparing widely disparate elements. When the disparity is great, the elements are placed in separate components of comparable size, giving rise to the idea of levels and their decomposition" (Saaty, 2010). If axiom 2 is not satisfied then the elements being compared are not homogeneous and clusters need to be formed.

Axiom 3 ***(Independence)***: This axiom assumes that criteria are independent of the properties of the alternatives in making comparisons and finding a set of global derived scale (rank order) for the alternatives can be assured. If axiom 3 is omitted, the principle of hierarchic composition would no longer apply because dependence among levels or components need not form a hierarchy.

Axiom 4 ***(Expectations)***: For the purpose of making a decision, the hierarchic structure is assumed to be complete. Expectations are that individuals who have reasons for their beliefs should make sure that their ideas are adequately represented for the outcome to match these expectations. That is, all alternatives and criteria are represented in the hierarchy and the hierarchic structure is assumed to be complete. Expectations are thus beliefs about the rank of alternatives derived from prior knowledge and are not only about the structure of a decision and its completeness, but also about the judgements and their redundancy to capture reality and inconsistency that should be improved with redundancy (Saaty, 2010).

4.3.2 AHP methodology

All four phases of the AHP methodology that include constructing a hierarchy of the problem to finally producing overall alternatives scores will be discussed below.

4.3.2.1 Structuring the decision problem

The design of a hierarchy to represent a decision problem is an influential part of the decision making. There is no set procedure for identifying the objectives, criteria, and the activities in a hierarchy. When constructing hierarchies one should include enough relevant aspects to represent the problem as systematically as possible, so that fulfilling Axiom 4, the hierarchy is complete. The important issues to be considered include the environment surrounding the problem, the issues or attributes that may contribute to the solution, and who are the participants associated with the problem. The goal, attributes, issues and stakeholders can be arranged in a hierarchy to serve two purposes: It provides an overall view of the complex relationship inherent in the situation and in the judgement process, and it also allows the decision maker to assess whether the issues being compared are homogeneous as mentioned in Axiom 2. Some suggestions to elaborate the design of a hierarchy are (Saaty and Vargas, 1994):

- Identify overall goal and subgoals. What is the main question;
- Identify criteria/subcriteria to be satisfied to fulfil the subgoals of the overall goal;
- Identify actors involved, their goals and their policies; and
- Identify options or outcomes.

A typical four-level hierarchy is shown in Figure 4.4, in which a decision problem is decomposed into a series of hierarchies. Each level of the hierarchy consists of a set of elements which in turn is decomposed into another set of sub-elements corresponding to the next level. The final level contains decision alternatives relative to the problem.

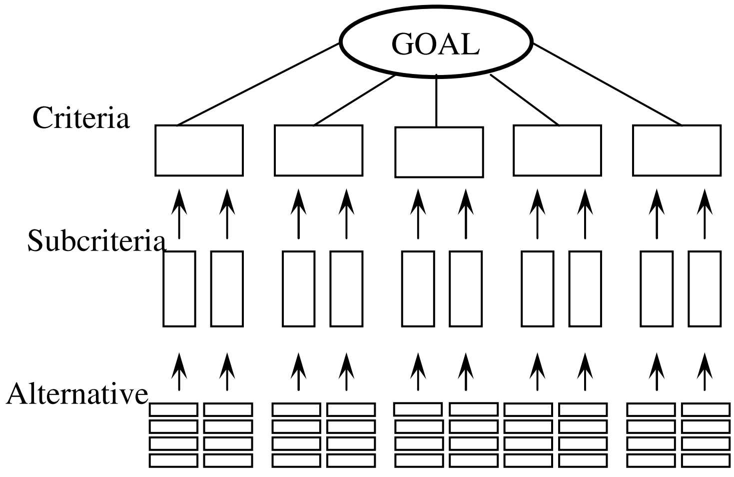


Figure 4.4 A four level hierarchy

4.3.2.2 Pairwise comparisons

After constructing the hierarchy describing the problem, the second phase is the measurement and data collection stage which involves conducting pairwise comparison. There are two kinds of comparisons that humans make: absolute and relative. Absolute measurement (also known by scoring) is applied to rank the alternatives in terms of either the criteria or the ratings of the criteria; e.g. excellent, very good, good, average, below average, poor and very poor. In absolute comparisons, alternatives are compared with a standard or a baseline which exists in one's memory and has been developed through experience. Relative measurement is applied in pairwise comparisons of two elements with respect to a common property. In relative comparisons, alternatives are compared in pairs according to a common attribute. The AHP has been used with both types of comparisons to derive ratio scales of measurement (Saaty, 1990).

Pairwise comparison is the process of collecting input data of decision elements so that ratio scale priorities can be derived. It is significant in decision-making problems, as it is normally impossible to select a specific alternative straightaway; there is rarely one alternative that is preferable in terms of all chosen criteria. In practice, it is common that certain options are better than others in terms of some criteria, while others are considered preferable in terms of the remaining criteria. This difficulty is resolved through pair-wise comparisons of alternative options (Giokas and Pentzaropoulos, 2008). It is therefore more scientific in deriving ratio scales because it uses a unit and estimates multiples of that unit rather than simply assigning numbers by guessing (Saaty, 2005). Also, it asks the question in a number of ways where a decision maker has to answer a question from different perspectives. This is seen as one of the benefits of the AHP/ANP because the preference vector is derived from a form of averaging and thus any error from a single data item is not disastrous (Yap et al., 1992). It is used to construct the essential comparison matrices of the AHP and ANP alike by relating the relative effect of elements in all levels. Such matrices are also used by other decision procedures, especially in evaluations by expert judges.

The comparison process requires a series of paired comparisons where the decision maker will compare two elements at a time with respect to a control/parent element. It involves comparing the relative importance, preference, or likelihood of two elements in response to a question. An example of a generic question is: How much more important is the element on the left side of the matrix compared with that at the top of the matrix? It is only necessary to make $n(n-1)/2$ comparisons to establish the full set of pairwise judgements for n elements. For m alternatives and n criteria, there is a need to create and process

$n(m\,x\,m)$ matrices. A matrix is a convenient form for pairwise comparisons as it is a simple, well-established tool that offers a framework for testing consistency, obtaining additional information through making all possible comparisons, and analyzing the sensitivity of overall priorities to changes in judgement (Saaty, 1980). The verbal terms of Saaty's fundamental judgement scale of absolute nine-point intensity shown in Table 4.1 are used to estimate the ratios as numbers, i.e. quantifying the relative importance of elements at each level of the hierarchy.

Table 4.1 The fundamental scale

Verbal Terms	Intensity	Explanation
Equally important	1	Two activities contribute equally to the objective
Moderately more important	3	Experience and judgement slightly favour one activity over another
Strongly more important	5	Experience and judgement strongly favour one activity over another
Very strongly more important	7	An activity is favoured very strongly over another and its dominance is demonstrated
Extremely more important	9	The importance of one activity over another is confirmed at the highest possible order
Intermediate Values	2,4,6,8	Used to represent a compromise between the priorities listed above
Reciprocals are used for inverse comparisons		If *i* is assigned a number between 1-9 when compared to *j*, then *j* takes the reciprocal

The scale translates the pairwise comparative judgements into intensity of relative importance represented by numbers to assess the intensity of preference between two elements (Saaty, 2005). The judgements are entered using the numbers 1, 3, 5, 7, and 9 which correspond to the verbal judgements. The values of 2, 4, 6 and 8 are intermediate values that can be used to indicate compromise values of importance between the five basic assessments.

To illustrate the above description, assume there are n elements $E_1, E_2, E_3 \cdots E_n$ and an expert is asked to provide pairwise comparison at a given level, expressing intensity of importance of one element in a pair over another with respect to a common property using the preference scale shown in Table 4.1. Hence, a judgement matrix A given in (1) is constructed by putting the results of pairwise comparisons in the position a_{ij} so that $A = (a_{ij})$, i.e. $n \times n$ matrix.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

All entries in this matrix are positive. The entry a_{ij} denotes the numerical value assigned by the expert to provide the relative significance (the intensity of importance) of the element E_i compared to element E_j. If both elements are equally important, then $a_{ij} = 1$ and, as all elements will always rank equally when compared to themselves, thus $a_{ii} = 1$, i.e. the diagonal entries will be equal to one. If E_i is more important than E_j, then $a_{ij} > 1$; and, if E_i is less important than E_j, then $a_{ij} < 1$. Matrix A is called a reciprocal matrix because according to Axiom 1, it satisfies the reciprocal property $a_{ji} = {}^{1}\!/_{a_{ij}}$. Reciprocal values are thus automatically entered in the transpose position. If judgements are perfect in all comparisons, then the transitivity rule $a_{jk} = {}^{a_{ik}}\!/_{a_{ij}}$ $i, j, k = 1, \cdots, n$ holds for all comparisons and A is called a consistent matrix (Saaty, 1980).

Once all pairwise comparisons are performed at every level and comparison matrices are constructed, a scale of relative priorities is derived from the paired comparisons. Hence, instead of assigning two numbers w_i and w_j forming the ratio w_i / w_j, a single absolute number from the fundamental scale (*that represents how many times the larger dominates the smaller)* is assigned to approximate the ratio $(w_i / w_j)/1$. It is a nearest integer approximation to the ratio w_i / w_j. Thus, the paired comparison process using actual measurement for the elements being compared, i.e. the weights $w = (w_1, w_2 \cdots w_n)$ are already known leading to the reciprocal matrix A shown in (2) (Saaty, 2005):

$$A = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \cdots & \cdots & \cdots & \cdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix} \quad (2)$$

Where: $a_{ij} = w_i / w_j$ for all $i, j = 1, 2, \cdots n$, and thus $a_{ij} a_{jk} = \frac{w_i}{w_j} \cdot \frac{w_j}{w_k} = \frac{w_i}{w_k} = a_{ik}$

And also: $a_{ji} = \frac{w_j}{w_i} \cdot \frac{1}{w_i / w_j} = \frac{1}{a_{ij}}$.

The above Saaty's concept leads to the approximation of the judgement matrix A shown in (1) by a matrix of ratios given in (2) whose elements are ratios of the measurements w_i / w_j of each n element with respect to all others. The entries in the matrix express the dominance of the element in the row heading over the element in the column heading.

4.3.2.3 Determination of normalised weights

The next phase of the process is to determine the normalised weights of the elements in a matrix, i.e. to produce priority vectors, or relative weights of the elements at each level of the hierarchy. In mathematical analysis, there are several computational algorithms for estimating the local priority vector w. The methods include (Zahedi, 1986): the arithmetic mean, the harmonic mean, the maximal eigenvalue, the geometric mean (also known as the logarithmic least squares (LLSM)), the mean transformation, the least squares, etc. (for a listing of other ways to approximate priorities, one can refer to Saaty, 1980). Although "no consensus exists on the choice of the estimator" (Zahedi, 1986), the eigenvalue (EV) (Saaty, 1980) and the geometric mean (GM) methods described below are widely applied, especially the EV method, which will be used to estimate the priority vectors in this study.

4.3.2.3.1 The eigenvalue method

The eigenvalue approach makes use of the information provided in the matrix whatever the consistency may be and derives priorities based on that information. It involves the calculation of the vector of the corresponding weights known as eigenvector w (also referred to as local priority vector) $= (w_1, w_2 \cdots w_n)$, assuming the actual relative weights $w_1, w_2 \cdots w_n$ of the n elements $A_1, A_2 \cdots A_n$ are known. Thus, the pairwise comparison matrix would be formed whose rows give the ratios of the weights of each element with respect to all others as shown in (2). Hence, multiplying the matrix A shown in (2) by the column vector $w = (w_1, w_2 \cdots w_n)$, yields the vector nw. That is:

$$Aw = nw \qquad (3)$$

Equation (3) is the formulation of an eigenvector problem; it can also be rewritten in elaborated but familiar matrix form as shown in (4):

$$Aw = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \cdots & \cdots & & \cdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ w_2 \\ \cdots \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ w_2 \\ \cdots \\ w_n \end{bmatrix} = nw \qquad (4)$$

However, if only A is given and w needs to be recovered (i.e. to recover the scale from the matrix of ratios), one must solve $Aw = nw$ or $(A - nI)w = 0$ in the unknown w.

Solving the homogeneous system of linear equations given in (3) to find w is a trivial eigenvalue problem. It has a nontrivial solution if and only if the determinant of $A - nI$ vanishes, that is, n is an eigenvalue of A. i.e. the existence of a solution depends on whether or not n is an eigenvalue (a root) of the characteristic equation of A (Saaty, 2005). Thus, as the elements on the diagonal of A consists of ones ($a_{ii} = 1$) and A is consistent, thus all its eigenvalues except one are zero. Also, it is known that: $\sum_{i=1}^{n} \lambda_i = tr(A) \equiv \text{sum of the diagonal elements} = n$, i.e. the sum of the eigenvalues of a matrix is equal to its trace, the sum of its diagonal elements, and in this case the trace of A is equal to n. Thus, only one of λ_i equals n, and so n is the largest or the principal eigenvalue of A and w is its corresponding principal eigenvector which can be made unique by normalising its entries (Saaty, 2005). Thus, given the comparison matrix, one can recover the scale. In this case, the solution is any column of A normalised. Given A, the reciprocal property $a_{ji} = 1/a_{ij}$ holds; thus, also $a_{ii} = 1$ and A is consistent: its entries satisfy the condition $a_{jk} = a_{ik}/a_{ij}$. Thus, the entire matrix can be constructed from a set of n elements which form a chain across the rows and columns (Saaty, 1980).

However, in the general case, the precise value of w_i/w_j is not given, but only an estimate of it obtained as a judgement and since the comparisons are carried out through personal or subjective judgements, some degree of inconsistency will occur. (i.e. real-world pairwise comparison matrices are very unlikely to be consistent). Thus, the existence of slight inconsistencies causes small perturbations of the eigenvalues and so priorities vary slightly according to the perturbation theory and yields (Saaty, 2005):

$$Aw = \lambda_{\max} w \tag{5}$$

Where A is the matrix of pairwise comparisons and $\lambda_{\max}$ is the largest eigenvalue of A. The value of $\lambda_{\max}$ is always greater than or equal to n, where n denotes the "number of activities in the matrix = number of rows = number of columns". There are several algorithms for approximating the priority vector w; one of them which is described below was used in this study. It is a two-stage algorithm known as the process of averaging over normalised columns and involves forming a new $n \times n$ matrix by following a three-step procedure (Saaty, 1980):

1. Add the elements of each column in the pairwise matrix;
2. Divide the value of each element in a column by its respective column sum obtained from step 1. This will produce the normalised comparison matrix; and
3. Average over the rows (obtaining the arithmetic mean) by summing the elements in each row of the resultant matrix and divide the sum by the n elements in the row to obtain the eigenvector.

It can be algebraically represented as:

$$w_i = \frac{\sum_{i=1}^{I}\left(\frac{a_{ij}}{\sum_{j=1}^{J} a_{ij}}\right)}{J} \tag{6}$$

Where:

w_i $\longrightarrow$ Weighted priority for component I;

J $\longrightarrow$ Index number of columns (components); and

I $\longrightarrow$ Index number of rows (components).

The resultant vector's normalisation condition is $\sum_{i=1}^{n} w_i = 1$ where its first entry represents the priority of the first activity, the second entry the priority of the second activity, and so on. Once w is estimated, the principal eigenvalue $\lambda_{\max}$ can be computed from it according to (5) by multiplying the pairwise comparison matrix by the right hand priority vector *w,* then dividing the resultant vector's first element by the priority vector's first element, second by the second and so forth with the others. Finally, averaging the final vector yields an approximate value of $\lambda_{\max}$. Alternatively, by multiplying the sum of each column vector in the reciprocal matrix by the priority of each row vector and summing, yields:

$$\lambda_{\max} = \sum_{i,j=1}^{n} s_j w_i \tag{7}$$

Where s_j is the sum of each column vector, w_i is the priority of each row vector.

Using the eigenvector to estimate the relative priorities of the elements being compared with respect to their parent elements leads to a natural measure of consistency for judgement matrices (Saaty, 1986), since $\lambda_{\max}$ is always greater than or equal to n for positive reciprocal matrices, and equal to n if and only if A is a consistent matrix, thus $\lambda_{\max} - n$ provides a useful measure of the degree of inconsistency. Normalising this measure by the matrix size as defined in Saaty (1990) gives the consistency index CI:

$$\mathrm{CI} = (\lambda_{\max} - n)/(n-1) \tag{8}$$

The consistency of the set of judgments is measured by the consistency ratio CR. Hence, in order to explain the consistency index given in (8) for a positive $n \times n$ reciprocal matrix A, one may consider the following simulation (Saaty, 2010):

Randomly, select the entries of A above the main diagonal from the 17 values $\{1/9, 1/8, 1/7, \ldots 1, 2, \ldots, 7, 8, 9\}$. Then, fill in the entries of A below the diagonal by taking reciprocals. 1s are put down the main diagonal and the consistency index is computed. Repeating this process 50,000 times and taking the average, i.e. mean CI value, which is known by the Random Index (RI), yields the values shown in Table 4.2, obtained from one set of such simulations.

Table 4.2 Random index

n 'order'	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.52	1.54	1.56	1.58	1.59
1st order differences	-	0	0.52	0.37	0.22	0.14	0.10	0.05	0.05	0.04	0.03	0.02	0.02	0.02	0.01

Table 4.2 above presents the average RI for matrices of various orders. Using these values, the consistency ratio (CR) of a pairwise matrix is defined as the ratio of its consistency index CI to the corresponding random index value RI shown in Table 4.2. That is:

$$\mathrm{CR} = {}^{\mathrm{CI}}\!/_{\mathrm{RI}} \tag{9}$$

Where:

RI denotes the average CI value of $n \times n$ random reciprocal matrices; and

The third row of Table 4.2 gives the difference among successive numbers in the second row.

The CR is a measure of how a given matrix compares to a purely random matrix in terms of their CI, i.e. a measure of pair comparison coherence.

Based on the above, the allowable ratio suggested by Saaty (2010), as a measure of the inconsistency in the judgements, should be not more than about 0.1. Typically, a value of $\mathrm{CR} \le 0.1$ is positive evidence for informed judgements and is taken as acceptable, whereas values of $\mathrm{CR} > 1$ require the decision maker to reduce the inconsistencies by revising judgements (Harker, 1987). The requirement of 10% cannot be made smaller such as 1% or 0.1% without trivialising the impact of inconsistency. However, inconsistency itself is important because without it, new knowledge that changes preferences cannot be admitted. Assuming that all knowledge should be consistent contradicts experience that requires continued revision of understanding.

If the maximum eigenvalue, CI and CR are satisfactory then the decision can be taken based on the normalised values. Otherwise, the procedure is repeated by soliciting a new comparison matrix until such values lie within the desired range. It is therefore very essential to treat problems related to consistency of the paired comparisons that may emerge during the assessment process before proceeding further in the analysis (see, Saaty 1996). If the CR is larger than desired, one can do the following (Saaty, 2010):

1. Find the most inconsistent judgement in the matrix (e.g. that judgment for which $\varepsilon_{ij} = a_{ij}\, w_j / w_i$ is largest).
2. Determine the range of values to which that judgment can be changed correspondingly, to which the inconsistency would be improved.
3. Ask the expert to consider, if s/he can, changing his/her judgment to a plausible value in that range. If s/he is unwilling, one can try with the second most inconsistent judgment and so on.

If no judgement is changed, the decision is postponed until better understanding of the stimuli is obtained.

Computing eigenvectors still can be a time consuming process. Fortunately, the mathematical procedures described above are nowadays implemented in software packages such as *Team Expert Choice, SuperDecisions, MATLAB®* that can be used to find the eigenvalues (the roots of any polynomial equation). Similarly, when the equation is the characteristic equation of a matrix, such packages can also find the eigenvectors.

In the next section, the geometric mean (GM) method will be explained.

4.3.2.3.2 The geometric mean method

The geometric mean method is another simpler way to obtain a good approximation of the priorities and gives a unique, geometrically normalised solution. It can be applied in calculation of the weight vector in paired comparisons evaluations in exactly the same way as the EV method but is developed from statistical considerations and can be easily calculated. It shares the desirable qualities of the EV in estimating the GM vector *w*. In fact, the geometric means of rows and columns provide the same ranking (which is not necessarily the case with the eigenvector method) (Crawford & Williams, 1985). In this study, the GM is used in aggregating individual judgements to represent a group judgement because it has been proved to be a unique way to do that (Saaty, 2001).

Referring to the matrices given in (1) and (2) above, and assuming A is consistent, then the normalised geometric mean which minimizes the distance between the two matrices in a logarithmic scale is (Kwiessielewicz, 1996):

$$I = \sum_{i,j>i}^{n} \left(\ln\left(a_{ij}\right) - \ln\left(\frac{v_i}{vj}\right) \right)^2 \qquad (10)$$

Letting $\mathrm{y}_{ij} = \ln(a_{ij})$ *and* $x_i = \ln(w_i)$ *for* $\forall i, j = 1,.....,n$, yields:

$$\min_{x,i=1,....,n} \left\{ I = \sum_{i,j=1}^{n} \left(y_{ij} - x_i + x_j\right)^2 \right\} \qquad (11)$$

Assuming that:

$$\prod_{i=1}^{n} v_i = 1 \qquad (12)$$

Referring to exponential $w_i = \exp(x_i), \quad a_{ij} = \exp(y_{ij}), \quad i, j = 1,......., n$, yields the geometric mean vector $v = (v_1, v_2 \cdots v_n)$:

$$v_i = \left(\prod_{j=1}^{n} a_{ij} \right)^{\frac{1}{n}}, \quad i = 1,......, n \qquad (13)$$

Computing the GM is done by multiplying the elements in each row and taking their *n*th root, where *n* is the number of elements. Then normalise to unity the column numbers thus obtained by dividing each entry by the sum of all entries. Alternatively, normalise the elements in each column of the matrix and then average each row (Saaty & Kearns, 1985). The resultant is not only the priority rank of each element but also the magnitude of its priority.

4.3.2.4 Synthesis – Finding a solution of the problem

The last phase of the process involves finding the global or composite normalised weights for alternatives at the bottom level in which Axiom 3 on independence governs this task. A single composite vector of unique and normalised weights for the entire hierarchy will be determined by multiplying the vectors of weights of the successive levels. The composite vector will then be used to find the relative priorities of all entities at the lowest level that enables the accomplishment of the stated objective of the problem. That is, after obtaining the weight vector; it is then multiplied with the weight coefficient of the element at a higher level (that was used as criterion for pairwise comparisons).

The procedure is repeated upward for each level, until the top of the hierarchy is reached. Thus, letting the local priority (preference score) of alternative i on criterion j be represented by s_{ij} and the weight of the criterion j by w_j, then for n criteria the global priority (overall score) of each alternative S_i is given by:

$$S_i = w_1 s_{i1} + w_2 s_{i2} + \quad .... \quad + w_n s_{in} = \sum_{j=1}^{n} w_j s_{ij} \qquad (14)$$

The overall weight coefficient with respect to the goal for each decision alternative is then obtained in the range: $0 < S_i < 1$. Subject to sensitivity analysis of the ranking produced by the model, the alternative with the highest weighted value is to be considered the preferred alternative (Pohekar and Ramachandran, 2004; Andrew et al., 2005).

4.4 The analytic network process

ANP is a multi-attribute decision making approach which was also developed by Thomas L. Saaty, as a theory of measurement used to derive priority scales of absolute numbers from individual judgements. It extends the AHP decision methodology which serves as a starting point of the ANP (originally called the supermatrix technique) to cases of dependence and feedback and generalises the supermatrix approach. Thus, the AHP becomes a special case of the ANP (Saaty, 2001). It overcomes the limitation of linear hierarchic structures as it uses a network without a need to specify levels as in a hierarchy and so levels are replaced by clusters as illustrated in Figures 4.1 and 4.2 that give an example of the network model in the ANP compared with a hierarchy in the AHP. Furthermore, the ANP includes interactions and feedback within clusters (inner dependence) and between clusters (outer dependence) and so can handle the complexities inherited in real-world problems. It provides a general systematic framework to include clusters of elements connected in any preferred way to investigate the process of deriving ratio scales priorities from the distribution of influence among elements and clusters.

In using the ANP to model an abstract decision problem, one needs to construct the network based on expert judgements and to compute the priorities of the elements. ANP joins all possible outcomes that can be thought of together in its structure and then both judgement and logic are used to estimate the relative influence from which the overall answer is derived. A network structure is composed of a goal, criteria and alternative clusters, along with connections among the elements to represent the problem. Connections among elements use arrows which can go both ways (feedback) and are made if elements of a given group influence elements of another group and vice versa. All connections that make sense can be treated as relations between elements. A cluster is a logical grouping of elements within a given decision. Clusters with elements may also have loops if their elements are internally dependent. The alternatives in the network may or may not include feedback to other components. “Not only does the importance of the criteria determine the importance of the alternatives as in a hierarchy, but also the importance of the alternatives themselves determines the importance of the criteria” (Saaty, 2010).

The next section will introduce a general approach in explaining the basic concepts of the ANP methodology. A particular focus will only be given to the aspects that differentiate ANP from AHP.

4.4.1 ANP methodology

In general, the process of the ANP is comprised of four major steps which are: network model construction, pairwise comparisons, supermatrix formation and synthesis (Chung et al., 2005; Meade & Sarkis, 1999; Saaty, 2005).

4.4.1.1 Network model construction

Once the selection criteria are identified, the problem is decomposed into a network where elements correspond to clusters. As explained in section 4.2, in order to establish relations and dependencies among the elements, the influences of elements in the feedback system with respect to common attributes are derived. This is essential because when a decision is to be made, influences spread as a network and thus there is a need to consider all potential influences and not simply the influences from top to bottom or vice versa as in a hierarchy (Saaty, 2001). Relationships among elements in the same cluster can exist and be represented by a looped arc. The elements in a cluster may also influence some or other elements in other clusters with respect to each of several properties. These relationships are represented by arcs with directions.

Assuming that a set of criteria has already been established, the input to ANP models is the decision maker’s answers to two kinds of questions of the general form with regard to the strength of dominance (Saaty, 2005):

- Given a criterion, which of two elements has greater influence (is more dominant) with respect to that criterion?
- Which of two elements influences a third element more with respect to a criterion?

It is essential to determine the approach to be followed in the analysis. Either the entire decision must use the idea of something “influencing” another (the most common and preferred approach). Otherwise it must use the idea of “influenced by” throughout the entire decision process as follows: Given a criterion and given an element X in any cluster, which of two elements in the same cluster or in a different cluster is influenced more by X with respect to that criterion? The main objective is to determine the overall influence of all elements and the resulting influences must be weighted by the importance of the criteria and added to obtain the overall influence of each element (Saaty, 2005).

4.4.1.2 Pairwise comparisons and priority vectors

Paired comparison judgements in the ANP are similar to the AHP and applied to pairs of homogeneous elements as discussed in subsection 4.3.2.2. The pairwise comparisons are performed within the structure so that elements of each cluster are compared pairwisely with respect to their impacts on an element in the cluster. In addition, pairwise comparisons are made for interdependency among elements outside clusters. When cluster weights are required to weight the supermatrix at the next stage, clusters are also compared pairwisely with respect to their impacts on each cluster. Hence, in order to derive the eigenvectors and to form a supermatrix, the following paired comparisons are to be performed:

- Cluster comparisons: Paired comparisons are performed on the clusters that influence a given cluster with respect to a control criterion. Weights derived from this process will be used to weigh the elements in the corresponding column blocks of the supermatrix corresponding to the control criterion;
- Comparisons of elements: Paired comparisons are performed on the elements within the clusters. Elements in a cluster are compared according to their influence on an element in their own cluster or in another cluster to which they are connected; and
- Comparisons of alternatives: Alternatives are to be pairwise compared with respect to all elements.

The way of conducting pairwise comparison and obtaining priority vectors is the same as discussed in the AHP section 4.3. However, in AHP/ANP the number of judgments and their validity are two constant concerns, particularly to users of the ANP. The number of pairwise comparisons necessary in a real problem often becomes overwhelming. For example, in AHP, with 9 alternatives and 5 criteria, the group must answer 190 questions. While there could some who would prefer not to burden the decision makers, others may be willing to spend more time on an important decision at the expense of putting forth too much effort.

Besides, no one would argue that with less information provided, the decision might not be as certain and robust as it would be if a thorough analysis were made. Thus, the question is 'what method can one use to expedite decision making without jeopardizing the quality of pairwise comparison judgments?' That is, why one would need all the $n(n-1)/2$ comparisons when it is easy to verify that only $n-1$ comparisons are enough to estimate the rest of the $n(n-1)/2$ comparisons (Triantaphyllou, 2000). As it is unknown whether or not a decision maker will be consistent, so all $n(n-1)/2$ judgements must be elicited. However, the completion of all these judgements, instead of only $n-1$ as in case of a decision maker who is perfectly consistent in his judgement, is an arduous task and a great deal of redundancy is created. In fact, such a redundancy plays a useful role to correct any errors in judgement, causing no great change to the final priorities of the elements (see Harker, 1987).

An algorithm for incomplete pairwise comparison, by which substantial time savings in using the AHP/ANP can be achieved, was introduced by Harker (1987 a & b). It can be summarised as follows:

- Obtain at least one judgement in each column creating a matrix with some unknown ratio elements. Enter zero for any missing judgement in this matrix and add the number of missing judgments in each row to the diagonal element in the row, producing a new matrix *A*;
- Calculate the weight *w:* $\lim_{k\to\infty}\frac{A^k e}{e^T A^k e} = cw$ and use the resulting w_i / w_j as a suggested value for the missing judgments to make it consistent with the judgements already provided;
- Obtain additional judgements that have the greatest influence on the weight *w*. A decision maker chooses for the next judgement that entry (i, j), with the largest sum of the absolute values of the coefficients of the gradient of *w* with respect to (i, j) calculated using: $D^A_{\lambda_{\max}} = \left[\frac{\partial \lambda_{\max}}{\partial_{ij}} i, j\right] = \left[(y_i x_j) - (y_j x_i)/a^2{}_{ij}, j > i\right]$

  Where:

  x: right principal eigenvector = w, in AHP notation $Ax = \lambda_{\max} x$

  y: left principal eigenvector $y^T A = \lambda_{\max} y$, y is normalised so that $y^T x = 1$.

  When an original $a_{ij} = 0$, it is replaced by the corresponding ratio w_i / w_j from *w*.

  Then $D^A_x = \left[\frac{\partial x}{\partial_{ij}}, j > i\right]$ is the matrix of gradients for the weights *x* and given by:

$$\begin{bmatrix} (\tilde{A} - \lambda_{\max} \tilde{I})^{-1} & \tilde{D}_{\lambda_{\max}} x - \tilde{z} \\ e & 0 \end{bmatrix}$$

Where:

$I = n$ x n identity matrix

$e = n$ dimensional row vector of ones

$z = (zk) = n$ dimensional column vector defined by: $zk = \begin{Bmatrix} x_j \ if \ k = i \\ -x_i / a^2{}_{ij} \ if \ k = j \\ o \ otherwise \end{Bmatrix}$

~ denotes the matrix of vector with its last row deleted.

D_x^A is a column vector whose elements either be +ve or –ve and their sum is 0.

It should be noted that the above method has not been used in this study, which relies on the complete set of pairwise comparisons.

4.4.1.3 Supermatrix formation and transformation

The local priority vectors are entered into the appropriate columns of a supermatrix which is a partitioned matrix that takes into account both inner and outer dependencies. The ANP uses the formation of a supermatrix to allow for the resolution of the effects of the interdependence that exists between the elements of the system. The supermatrix resembles the Markov chain process (Saaty, 2005) and summarises all influences where each submatrix is composed of a set of relationships between clusters/levels. It is normally arranged in the form of components with the clusters in alphabetical order across the top and down the left side, and with the elements within each cluster in alphabetical order across the top and down the left side. A component in a supermatrix is therefore the block defined by a cluster name at the left and a cluster name at the top (Adams and Saaty, 2003). There are three supermatrices associated with each ANP network: unweighted, weighted and limit supermatrices (Saaty, 2005).

Assuming the supermatrix of a system of N clusters is denoted as shown in Figure 4.5, C_k, is the *kth* cluster *(* $k = 1, ..., N$ *)* which has n_k elements denoted as $e_{k1}, e_{k2}, ..., e_{kn_k}$. It is used to represent the flow of influence from a component of elements to itself (as in the loop shown in Figure 4.2 which flows back to C_4), or from a component from which an arrow is directed out to another component.

$$
W = \begin{array}{cc}
 & \begin{array}{cccc} C_1 & C_k & & C_N \\ e_{11}\, e_{12} \ldots e_{1n1} & \ldots e_{k1}\, e_{k2} \ldots e_{knk} & \ldots & e_{N1}\, e_{N2} \ldots e_{NnN} \end{array} \\
\begin{array}{cc} C_1 & e_{11} \\ \vdots & \vdots \\ & e_{1n1} \\ & \vdots \\ C_k & e_{k1} \\ \vdots & \vdots \\ & e_{knk} \\ & \vdots \\ & e_{N1} \\ C_N & \vdots \\ & e_{NnN} \end{array} & \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1N} \\ W_{21} & W_{22} & \cdots & W_{2N} \\ \cdots & \cdots & \cdots & \cdots \\ W_{N1} & W_{N2} & \cdots & W_{NN} \end{bmatrix}
\end{array}
$$

Figure 4.5 The supermatrix of a network

A matrix segment w_{ij} which represents a relationship between the *ith* cluster and the *jth* cluster is illustrated in Figure 4.6.

$$
W_{ij} = \begin{bmatrix} W_{i1}^{(j_1)} & W_{i1}^{(j_2)} & \cdots & W_{i1}^{(jn_j)} \\ W_{i2}^{(j_1)} & W_{i2}^{(j_2)} & \cdots & W_{i2}^{(jn_j)} \\ \cdots & \cdots & \cdots & \cdots \\ W_{in_i}^{(j_1)} & W_{in_i}^{(j_2)} & \cdots & W_{in_i}^{(jn_j)} \end{bmatrix}
$$

Figure 4.6 An example details a matrix in the supermatrix

Each column of w_{ij} is a local priority vector derived from paired comparisons in the usual way of the AHP (as explained in section 4.3.2.3). When there is no relationship between clusters, the corresponding matrix segment is a zero matrix (Saaty, 2006). Therefore, it is only those elements that have non-zero influence that need to be used in a component when making pairwise comparisons to derive the priority vectors. Since all the local priority information can be read directly from this non-column stochastic supermatrix (i.e. its columns may not sum to one because each column consists of several eigenvectors, which each sums to one, and hence the entire column of the matrix may sum to an integer greater than one) it is called the unweighted (original) supermatrix.

Next, the supermatrix is transformed into the weighted supermatrix. This can be done by determining a cluster priority vector for each cluster (which indicates the relative importance of influences of other clusters on each cluster) by conducting pairwise comparisons among clusters with respect to the column cluster. The resulting priority vector is used to weigh the matrix segments that fall in the column under the given cluster by multiplying all the elements in a component of the unweighted supermatrix by the corresponding cluster weight. The first entry of the vector is multiplied by all the elements in the first matrix segment of that column, the second entry by all the elements in the second segment of the column and so on. Repeating this weighting procedure for all the column clusters produces the weighted supermatrix in which all columns sum to unity and so are 'column stochastic'. This feature of the weighted supermatrix is needed because the elements are compared among themselves and information is needed about the importance of the clusters to which they belong, to determine their relative overall weight among all the elements in the other clusters. It also allows for the convergence to occur in the limit supermatrix.

Finally, the weighted supermatrix is transformed into the limit supermatrix by raising itself to power 2^{k+1}, where k is an arbitrarily large number, to allow for convergence of the interdependent relationships. The rationale for multiplying the weighted supermatrix is to capture the transmission of influence along all possible paths of the supermatrix. The entries of the weighted supermatrix represent only the direct influence of any element on any other element, but an element can influence a second element indirectly through its influence on a third element that has the direct influence on the second element. Such one-step indirect influences are captured by squaring the weighted supermatrix, and two-step indirect influences are obtained from the cubic power of the matrix, and so on. The convergence of the matrix means the row values converge to the same value for each column of the matrix. The resulting matrix is called the limit supermatrix, which yields limit priorities capturing all the indirect influences of each element on every other element (Saaty, 2005). The construction of the supermatrices in the ANP requires a computer support largely than hierarchically structured problems. Hence, *SuperDecisions* has the facility to account for such complex computations.

4.4.1.4 Synthesis

Although the ANP and the AHP are similar in the comparative judgement phase, they differ in the synthesis phase. Hence, once the supermatrix covers the whole network, the final priorities of all the elements are found in the corresponding columns in the limit supermatrix. With the priorities normalised by the cluster, the columns of the limit supermatrix are all the same. All elements' priorities can be read from any column and the alternative with the highest priority is to be selected. If a supermatrix only includes interrelated components, additional calculation should be made.

4.4.1.5 Sensitivity analysis

Sensitivity analysis helps determine the robustness of a model. It tests a plausible range of values for each criterion to determine how sensitive the outcomes are to changes in the inputs' estimate. Through sensitivity analysis, decision makers can discover how changes in judgements or priority about the importance of each criterion might affect recommended decisions (Saaty, 2008). Hence, after obtaining the final priorities, it is often desirable to test the responsiveness or sensitivity of the outcome of a decision to changes in the priorities of the major criteria of that problem. What one does is to change the priority of that criterion keeping the proportions of the priorities for the other criteria the same so again they all (including the changed criterion) add to one. The results of sensitivity are to be interpreted by noting how stable this outcome is, and comparing it with the other outcomes by taking ratios and observing how large or small these ratios are (Adams and Saaty, 2003).

The *Expert Choice* and *SuperDecisions* have several ways to display the results of such sensitivity changes.

4.4.2 The ANP 'BOCR' method

A decision has several favourable and unfavourable concerns to consider, in which some of these are sure things, while others are less certain. Hence, the favourable sure things are called 'Benefits' while the unfavourable ones are termed 'Costs'. The uncertain concerns of a decision are the positive 'Opportunities' that the decision might create and the negative 'Risks' that it can entail (Saaty, 2010). The four concerns utilises a separate structure for the decision and are referred to collectively as BOCR (i.e. using the initials of the positive ones before the initials of the negative ones).

The general theory of the ANP model, which consists of a goal, and four separate BOCR models (subnets) will be used later for modelling the selection problem. The benefits model shows which alternative would be most beneficial, i.e. yield the most benefits, and the opportunities model shows which alternative has the greatest potential for benefits, i.e. offers the most opportunities, where as the costs model (costs may include monetary, human, and intangible costs) shows which alternative would be most costly and finally, the risks model shows which alternative has the highest potential risks, i.e. pose the most risk for each alternative. Opportunities and risks are considered as 'hidden' benefits and costs, respectively (Saaty, 2001). Each BOCR model should have some control criteria (subcriteria) in it to be evaluated with. BOCR is then performed as an analysis to weigh these categories. They are the criteria which one can use to represent the different kinds of influences that can be perceived. They will later need to be combined into an overall influence using the usual AHP/ANP calculations. The analysis will derive four rankings of the alternatives, one for each of the BOCR merits. Two formulas can be used for synthesis; one multiplicative and one additive subtractive.

The ANP 'BOCR' approach consists of the following steps (Saaty, 2001):

1. Define a decision making problem and present it as in the case of the AHP, in the form of a general goal to be achieved;
2. Decompose the problem into a network with four sub-networks, namely: Benefits (B), Opportunities (O), Costs (C) and Risks (R). BOCR should jointly contribute to the achievement of the main ultimate goal defined in step (1);
3. Build individual BOCR hierarchical structures. For each structure, define control elements (criteria and subcriteria);
4. Pairwise compare the elements in each level with respect to the same upper level element (compare criteria to the control goal of BOCR, subcriteria to criteria), and the interdependence among the elements. More specifically, for Benefits and Opportunities: Ask what gives the most benefits or presents the greatest opportunity to influence the criterion (subcriterion); for Costs and Risks: Ask what incurs the most cost or faces the greatest risk.
5. Calculate priorities in each subnetwork. Calculate global priorities by multiplying the priority of the subcriteria by the priority of the respective criterion and divide by 4 (B, O, C and R). It is recommended for further analysis to select only those subcriteria that have global priorities above 3% in case of a large number of subcriteria (i.e. >20) or 5% in case of a small number of subcriteria (i.e. <15);
6. Produce a general network consisting of clusters and elements that contribute to all control criteria;
7. For the most significant subcriteria (i.e. global priorities > 3%), create subnets. Each subnet should consist of the Alternatives' cluster and clusters with other elements such as influencing factors, stakeholders of decision making process, their objectives and point of view, etc. Define their influences and feedbacks. Note that each subnet must include the Alternatives cluster which are the same in any subnet, while other elements may differ;
8. Pairwise compare the elements within and among the clusters (always considering the upper criterion and BOCR within which the comparison takes place). Pairwise compare the clusters in respect to how much they influence a particular control criterion;

9. Calculate the priorities of alternatives for each *B, O, C, R* network. Using the priorities obtained in step (5), form an unweighted supermatrix (ideal values), a weighted supermatrix and a limit supermatrix for each subnetwork by ANP. The priorities of the alternatives under each merit are calculated by normalising the alternative-to-goal column of the limit supermatrix of the merit;
10. Calculate overall priorities of alternatives by synthesising priorities of each alternative under each merit from step (9) with corresponding normalised weights b, o, c, and r from step (5). There are two ways commonly used to combine the scores of each alternative under *B, O, C,* and *R:*
    i. *Multiplicative* $(P_i = B_iOi / C_iRi)$
    ii. *Additive-negative* $(P_i = bB_i + oOi = c(1/C_i)_{Normalised} + r(1/Ri)_{Normalised}$

    The additive formula requires determining of the importance of each subnetwork: B, O, C, R based on the so called strategic criteria as explained in steps (11-13);
11. Determine the priorities of the strategic criteria. Build another hierarchy consisting of elements that are more general to allow analysis of the problem from more general perspective. Likewise, in the AHP, the nine-point scale should be used to obtain pairwise comparison results of the importance of strategic criteria toward achieving the overall objective. Calculate the priorities of the strategic criteria and examine the consistency property of the matrix;
12. Using a five-step scale (very high, high, medium, low, very low) indicate the importance of B, O, C, and R with respect to each strategic criterion. Ready values can be adopted which have been calculated as follows (Saaty, 2008): very high – 0.42, high – 0.26, medium – 0.16, low – 0.10, and very low – 0.06;
13. Determine the priorities of the B, O, C, R. Calculate the priority of a merit by multiplying the score of a merit on each strategic criterion from step (4) with the priority of the respective strategic criterion from step (3) and summing up the calculated values for the merit. Normalise the calculated values of the four merits, and obtain the priorities of the *B, O, C, R,* that is b, o, c and r, respectively;
14. Synthesise the whole model by applying the above explained formulae (additive-negative and multiplicative). The alternative with the highest values is the best one that contributes most to the achievement of the main goal; and
15. Conduct sensitivity analysis to test the stability of the model.

4.5 Group decision making

A decision carries a lot more weight when a group makes it than when just one person does. However, a group decision making process needs to be managed to take advantage of the plurality of its members. This is because disputes may arise regarding values, beliefs about the consequences of a decision, and preferences for certain alternatives. Hence, there is a need for a method of synthesis that tolerates some level of disagreement without affecting the validity of the outcome. The method must be able to incorporate a situation when different people with different levels of authority and expertise and different strengths of opinions can affect the outcome differently. It is essential to quantify such intensities numerically in order to combine them and trade them off.

The reciprocal property plays an important role in combining the judgements of several individuals to obtain a judgement for a group. Judgements can be combined by the geometric mean so that the reciprocal of the synthesised judgements must be equal to the syntheses of the reciprocals of these judgements (Saaty, 2001). While the geometric mean satisfies the reciprocal relation, the arithmetic mean does not satisfy this relation. For example, three experts estimating how many times the Satellite technology is scalable than the Microwave, their judgments were twice larger, three times larger and four times larger, respectively. Thus, the geometric mean of these judgments is $(2 \times 3 \times 4)^{1/3} = 2.88$ and the reciprocal of the synthesised judgments is $1/2.88 = 0.3467$, which is also equal to the syntheses of the reciprocals of these judgments $(1/2 \times 1/3 \times 1/4)^{1/3} = 0.3467$, while the arithmetic mean is $(2+3+4)/3 = 3$ but the reciprocal of $3 = 0.3333 \neq (1/2+1/3+1/4)/3 = 0.3611$. The basis for using this method has been justified mathematically by Aczel and Saaty (1983) and Saaty (2001).

In addition, the need for a support system to facilitate the process is inevitable. Fortunately, in the era of information technology and the internet, it has become unnecessary for everyone to be present together in a room to make a collective decision. With the appropriate software, it is possible to distribute the tasks for the decision while keeping the whole process coherent.

In the following subsections, two methods in group decision making are presented. The first is how to aggregate individual judgements, and the second is how to construct a group choice from individual choices.

4.5.1 Aggregating individual judgements

In group decision making, if the individuals giving judgements are experts, they may not prefer to combine their judgements but only aggregate their final outcome from a hierarchy. Hence, one can mathematically synthesize individual judgements, which allows the construction of a cardinal group decision compatible with the individual preferences by forming the geometric mean of the final outcomes (Saaty, 2001).

Let the function $f(x_1, x_2, ..., x_n)$ for synthesizing the judgements given by *n* judges, satisfy the following (Saaty, 2006):

i. Separability condition (S): $f(x_1, x_2, ..., x_n) = g(x_1)\,g(x_2)...\,g(x_n)$ for all $x_1, x_2, ..., x_n$ in an interval P of positive numbers, where *g* is a function mapping P onto a proper interval J and is a continuous, associative and cancellative operation. [(S) means that the influences of the individual judgements can be separated as above];

ii. Unanimity condition (U): $f(x, x, ..., x) = x$ for all x in P. [(U) means that if all individuals give the same judgement x, that judgement should also be the synthesized judgement];

iii. Homogeneity condition (H): $f(ux_1, ux_2, ..., ux_n) = uf(x_1, x_2, ..., x_n)$ where $u > 0$ and x_k, ux_k $(k = 1,2,...,n)$ are all in P. [For ratio judgements (H) means that if all individuals judge a ratio *u* times as large as another ratio, then the synthesized judgement should also be *u* times as large]; and

iv. Power conditions (P_p): $f(x_1^{p}, x_2^{p}, ..., x_n^{p}) = f^{p}(x_1, x_2, ..., x_n)$ [(P_2) for example means that if the *kth* individual judges the length of a side of a square to be x_k, the synthesized judgement on the area of that square will be given by the square of the synthesized judgement on the length of its side].

4.5.2 Constructing group choice from individual choices

In collective social choice problems, there is a need to develop a procedure or rule that can suitably assist in aggregating individual preferences representing the preferences of the group as a whole. Given a group of individuals, a set of alternatives A and B, and the individuals' judgements of preference between A and B, Arrow (1963) proved with his Impossibility Theorem that it is impossible to derive a rational group choice (i.e. construct a social choice function that aggregates individual preferences) from ordinal preferences of the individuals that satisfy the following four conditions (known as Arrow's four conditions), i.e. at least one of them is violated (Saaty, 2008):

i. Decisiveness: The aggregation procedure must generally produce a group order;

ii. Unanimity (Pareto optimality): If all individuals prefer A to B, then the aggregation procedure must produce an order indicating the group prefers A to B;

iii. Independence from irrelevant alternatives: Given two sets of alternatives which both include A and B, if all individuals prefer A to B in both sets, then the aggregation procedure must produce a group order indicating that the group, given any of the two sets of alternatives, prefers A to B; and

iv. No dictator: No single individual determines the group order.

However, Saaty (2008) proved that for the AHP/ANP, using absolute scales, the impossibility is removed once and for all, i.e. using a ratio scale approach, in which the individual preferences are cardinal rather than ordinal, it is possible to derive a rational group choice satisfying the Arrow's four conditions above because:

a) Individual priority scales can always be derived from a set of pairwise cardinal preference judgements as long as they form at least a minimal spanning tree in the completely connected graph formed by the elements being compared; and

b) The cardinal preference judgements associated with group choice belong to a ratio scale that represents the relative intensity of preferences of the group.

Thus, an aggregation procedure that produces a group choice is considered satisfactory if (Saaty, 2008):

- It responds, at least not negatively, to changes in individual preferences;
- It reflects the collective opinion of the individuals; and
- It provides ranking for the various alternatives of a decision that the group faces.

4.6 Conclusion

This chapter covered two methods: the AHP and the ANP. Initially, the concepts of hierarchies and networks were introduced. It is believed that the main aim of a hierarchy is to understand the goal based on the interactions of the various levels, rather than directly from the elements of the levels. A gradual increase of the number of hierarchical connections generates a network, which has a non-linear structure. A network spreads out in all directions introducing a free form of ordering elements, in contrast to a predetermined importance chain as in a hierarchy.

The well-known AHP theory was described together with the principles and axioms of AHP. Three principles in problem solving constitute the basis of the AHP. These are decomposition or hierarchic design, comparative judgement and synthesis of priorities or hierarchic composition. These principles are supported by four axioms concerned with the reciprocal relation, comparison of homogenous elements, hierarchic and systems dependence, and expectations about the validity of the rank and value of the outcome and their dependence on the structure used and its extension.

The AHP methodology was explained phase by phase to show it could handle both qualitative and quantitative criteria in a problem. In the structuring of the decision problem stage, one should include enough relevant aspects to represent the problem as systematically as possible. There is no set procedure for identifying the objectives, criteria, and the activities in a hierarchy. Some suggestions to elaborate the design of a hierarchy include identifying an overall goal and subgoals, identifying criteria and their subcriteria to be satisfied in order to fulfil the subgoals of the overall goal, identifying actors involved and identifying options or outcomes.

Pairwise comparisons of elements were discussed, which involve collecting input data of decision elements so that ratio scale priorities can be derived. They are used intensively as the means for extracting the pertinent data for many decision-making problems allowing for imprecise judgments of an expert to be processed and accurate estimates of the unknown parameters to be derived. Decision makers can therefore avoid the use of intuition, which may be biased by personal preferences. It was pointed out that the comparison process involves comparing the relative importance, preference, or likelihood of two elements in response to a question. A scale of absolute nine-point intensity is used to estimate the ratios as numbers, i.e. quantifying the relative importance of elements.

In order to determine the normalised weights to produce priority vectors, or relative weights of the elements, several computational algorithms can be used. The most widely applied ones are the eigenvalue and the geometric mean methods described in this chapter. In particular, the eigenvector approach which has been used to estimate the priority vectors in this study. Fortunately, eigenvectors' computations are nowadays implemented in software packages such as *Team Expert Choice*, *SuperDecisions,* and *MATLAB*®.

As in the general case, the precise values of the ratios of the weights are estimated as judgements and since the comparisons are carried out through personal or subjective judgements, some degree of inconsistency is inevitable. The consistency of the set of judgments was discussed in this chapter. It is measured by the consistency ratio (CR), which is a measure of how a given matrix compares to a purely random matrix in terms of their consistency index (CI), i.e. a measure of pair comparison coherence. Typically, a value of $CR \leq 0.1$ is positive evidence for informed judgements and the decision can be taken based on the normalised values, whereas values of $CR > 1$ require revising judgements to reduce the inconsistencies.

The computation of the global or composite normalised weights for alternatives was described in this chapter. A single composite vector of unique and normalised weights for the entire hierarchy was determined by multiplying the vectors of weights of the successive levels. It was then multiplied with the weight coefficient of the element at a higher level. The procedure was repeated upward for each level, until the top of the hierarchy was reached.

The AHP is a special case of the ANP that can be very useful for incorporating linkages in the system by dealing systematically with all kinds of dependence and feedback within its structure. The ANP was presented in the second part of the chapter, which started by introducing a general approach in explaining the ANP basic concepts. The ANP methodology comprises of four major steps: network model construction, pairwise comparisons, supermatrix formation and synthesis. The process of developing a model that includes clustered criteria and dependencies among the different elements in the network was explained. The network structure is described by clusters of elements connected by their dependence on one another in which at least one element in each of these clusters is connected to some element in another cluster. These connections indicate the flow of influence between the elements.

Pairwise comparisons are made based on the dependencies among all elements in order to develop the unweighted supermatrix that contains the local priorities. Clusters are also pairwise compared and their weights are used to weight the unweighted supermatrix resulting in a stochastic weighted supermatrix. The way of conducting pairwise comparison and obtaining priority vectors is the same as was discussed in the AHP. However, in ANP the number of judgments and their validity are two constant concerns, particularly to users of the ANP because the number of pairwise comparisons necessary in a real problem which often becomes overwhelming. Hence, an algorithm for incomplete pairwise comparison by which substantial time savings in using the AHP/ANP can be achieved was introduced.

Finally, to synthesise the network, the ANP uses the formation of a supermatrix to allow for the resolution of the effects of the interdependence that exists between the elements of the system. The supermatrix resembles the Markov chain process and summarises all influences where each submatrix is composed of a set of relationships between clusters/levels. Three supermatrices are associated with each ANP network: unweighted, weighted and limit supermatrices. The weighted supermatrix is raised to arbitrarily large powers until it converges and the limit matrix is obtained. The priorities of all elements in the network, in particular the alternatives, can be read from any column.

After obtaining the final priorities, it is often desirable to test the robustness of a model and the responsiveness of the outcome of a decision to changes in the priorities of the major criteria of the problem. Sensitivity analysis helps decision makers to test a plausible range of values for each criterion to determine how sensitive outcomes are to changes in the inputs' estimates. It also allows them to discover how changes in judgements or priority about the importance of each criterion might affect recommended decisions.

Generally, a decision has several favourable aspects called 'Benefits' (B) and unfavourable concerns termed 'Costs' (C). The uncertain concerns of a decision are the positive 'Opportunities' (O) that the decision might create and the negative 'Risks'(R) that it can entail. The four concerns utilises a separate structure for the decision and are referred to collectively as BOCR. All BOCR-based ANP approach steps were introduced. This method will be the subject of chapter 7.

In this chapter, two methods in group decision making were presented. The first is how to aggregate individual judgements, in which one can mathematically synthesize individual judgements that allow for the construction of a cardinal group decision compatible with the individual preferences by forming the geometric mean of the final outcomes. The second method is how to construct a group choice from individual choices provided that an aggregation procedure produces a group choice, which is considered satisfactory.

In summary, the study of ANP methodology shows that it is a systematic tool for solving complex decision problems. It helps decision makers to understand the problem in depth during the process of breaking down the problem into a network. It is a powerful tool in decision-making processes and can model the problem of this study, which is complex and multicriteria in nature. To ensure that the outcome of the model is not constructed as a result of unusual judgements, *SuperDecisions* can be used to perform comprehensive sensitivity analysis on the final outcome to determine how much effect a change in judgements would have on the final decision.

5. IDENTIFICATION OF SELECTION CRITERIA AND ALTERNATIVES

5.1 Introduction

The choice of appropriate infrastructure technologies for rural telecommunications access is dictated by a number of basic parameters, such as population density, terrain, distance, power supply, network configuration, etc. From a technicality point of view, and in order to be economically attractive, rural telecommunications systems should satisfy certain technical conditions. Proper decisions need to be made to ensure the provision of the most efficient network and most effective system within several constraints (ITU-D, 1997). In fact, many of the problems facing rural areas are outside the scope of telecommunications alone to resolve and require coordination of several other sectors such as rural electrification, transport network development, education and training programs, etc.

This chapter introduces various major factors that generally face planners of rural infrastructure, and in particular, factors that affect the selection of rural telecommunications technologies. It presents an explanation of the activities that were used as means to consolidate the final list of selection criteria. These include the intensive literature survey and the interaction with the experts in the field. The online survey, which has been conducted in order to identify the importance of the adopted criteria, is described.

An analysis of the results is given followed by grouping of criteria into clusters according to their importance. A description of the various activities used to identify potential infrastructure technology alternatives in the context of how it can be deployed in rural areas is presented. Four traditional technologies have been chosen as candidate decision alternatives for this research and a brief comparison between them is given. A description of the selection criteria and the alternatives used in this study is given in appendix A. To summarise the findings of this chapter, a conclusion is finally presented.

5.2 Setting selection criteria

In order to adopt and apply the AHP/ANP methodologies for such a technology selection process, it is the foremost activity of the researcher to examine the issues involved in the selection and deployment of rural telecommunications technologies. Hence, the dilemma is the definition of the criteria and weights that will be used for the choice of the appropriate technology for rural connectivity. It must be a set of well-thought requirements that can best represent the benefits of all stakeholders, looking for a selection model aligned with their strategies. Therefore, as said earlier, there is a need to consider social, environmental, economic, regulatory, cultural and technical issues before deciding on a specific rural telecommunications technology. This is deemed necessary to enrich the set of selection criteria to be used in determining the relative merits of one technology versus the others, to come up with the most viable and applicable choice. “Perhaps the most creative task in making a decision is to choose the factors that are important for that decision” (Saaty, 1990). The goal of the aimed selection model is to address the question, “How should rural telecommunications infrastructure providers select the most appropriate backbone infrastructure technology in rural areas of the developing countries?”

Several factors that explicitly consider many of the rural telecommunications technology selection issues are used to develop the decision model. It is recognized that each telecommunication infrastructure provider will have its own set of criteria and that the model for a particular situation may use other factors. The attempt here is to present a generalised model based on factors and alternatives identified from the published literature and best practices as well as from telecommunications experts that could then be adapted or extended to support a particular context or a situation of a developing country. Final alternatives scores should, however, be thought of as an input to the decision-making process rather than its end.

The activities described below that include an intensive literature review and exploring experts’ views were used as means to consolidate the final list of selection criteria.

5.2.1 Literature review

An intensive literature survey was conducted to seek information about potential selection criteria. Previous studies and research on similar technology selection problems were used as secondary sources and reviewed in order to reveal related selection criteria for the problem at hand. It has been found that the key criteria for the selection of telecommunications infrastructure technology designed to extend e-services applications to rural areas are based on cost, quality, and speed attributes (see e.g. Douligeris and Pereira, 1994; Min et al., 2001, Sasidhar and Min, 2005).

Andrew et al. (2005) identified 51 different criteria and subcriteria for the selection. They include the technology’s application, projected life cycle, its costs and payback in terms of useful life, and its social, political and economic impact. The study of Chemane et al. (2005) identified a number of criteria with respect to financial and technical aspects. Based on the analysis of the second series of the collected case studies of the ITU global survey, on the reality of rural communications of developing countries, Kawasumi et al. (2008)

reported certain relevant criteria for the choice of technologies in rural and remote areas. These include: country size, topographic conditions, policy framework, availability of spectrum, population density and availability of backbone network. Therefore, some of the abovementioned related factors formed the basis for identifying other important infrastructure technology selection criteria.

5.2.2 Experts' views

A number of online forums that bring together telecommunication experts from all over the world were used to seek inputs from experts. LinkedIn® is one of such forums that was of great use in communicating with them. It is an online network of more than 30 million experienced professionals, from around the world, representing 150 industries. The author used his profile to ask several questions related to his research. This process was successful in finding subject experts from companies that provide rural telecommunications infrastructure technologies. Also, by inviting experts to connect, one can form a network which consists of one's connections, one's connections' connections, and the people they know, eventually linking one to thousands of qualified telecommunications professionals.

In parallel with the aforementioned activities, the following question which is related to the selection criteria was addressed to rural telecommunication experts:

"What are the criteria for the selection of the most appropriate rural telecommunication infrastructure technology to provide e-services in rural areas of developing countries?"

The question has been published on two different telecoms forums. Their links are:

- *http://www.linkedin.com/answers/technology/information-technology/telecommunications/TCH_ITS_TCI/238592 25439845?browseIdx=4&sik=1226598150118&goback=%2Eamq*
- *http://erlang.com/forum/erlang/thread.htx?thread=4183*

The purpose of posting such a question is to identify relevant technology selection criteria based on expert opinions. Within a period of one week, thirteen experts had positively responded with their opinions and contributions. Most of the inputs are considered very relevant to the subject matter, in which some emerging factors have been included in the list of the selection criteria.

In addition, an interaction via e-mail with several experts in the field of rural telecommunications, both from industry and academia, helped to come up with an initial list of factors, which represents the important criteria for the selection of rural telecommunications infrastructure technology. All the different factors were initially compiled in that list without paying attention to any overlapping or redundancy. After this, a regrouping and development of additional specific criteria were completed with the aid of several telecommunications experts scattered across a wide geographic region throughout the world. Those experts were sent copies of the initial list of various selection factors and their definitions. During the process of providing definitions, a consensus was reached on which factors to include, using e-mail and returned comments from them.

The process continued until all technology selection factors that need to be considered were included in the structure. A number of iterations (approximately 4 to 5) were needed to make sure all factors are determined. For example, after obtaining feedback from experts, economic development of target area was included among the factors to be used in the model.

In order to keep the number of factors at a manageable level, it was winnowed down to those that were viewed as most important to the decision at hand. For example, for the community of interest criterion, Andrew et al. (2005) provides a number of subcriteria which were kept out of the ANP model, in order to limit the number of comparisons. Finally, from the aforementioned activities, it was possible to consolidate a list of 31 selection criteria, deemed to affect the telecommunications planners' decision in the choice of rural telecommunications backbone infrastructure as shown in Table 5.1. The criteria incorporate hard to quantify as well as easy to quantify criteria simultaneously. A description of all criteria is given in Appendix A.

Table 5.1 Final list of selection criteria

Criteria		
Funding sources		Rollout time
Capital cost		Parallel infrastructure
Operating cost		Terrain topography
Return on investment		Climatic conditions
Funding sources		Remoteness of area
Economic development of area		Coverage range
Bandwidth		Proposed usage
Latency		Existing telecoms infrastructure
Reliability		Population density
Flexibility		Demand
Scalability		Community of interest
Compatibility		Affordability
Ease of installation		Spectrum availability
Ease of maintenance		Rights of way
Remote network management		Licensing constraints
Security of physical infrastructure		-

The following section discusses the process of identifying the most important criteria, assessing, rating and ranking them according to their importance from a perspective of telecommunication experts.

5.3 The online survey

In order to rank the criteria for rural telecommunication infrastructure technology selection according to their relative importance, an online questionnaire, shown in Appendix B has been designed to fulfil this task. It is mainly addressed to telecommunication experts and consists of the 31 factors given in Table 5.1. It used a five-point Likert-type scale shown in Table 5.2 to obtain a range of diversified expert opinions with respect to each particular selection factor, ranging from 'Not important', 'Moderately important', 'Strongly important', 'Very strongly important' and 'Extremely important'.

Table 5.2 Five-point assessment scale

Score	1	2	3	4	5
Verbal assessment	Not important	Moderately important	Strongly important	V. strongly important	Extremely important

To ensure the reliability of the questionnaire and to avoid any ambiguities, a pilot test was conducted before posting the questionnaire online. It included two staff members in the School of Electrical and Electronic Engineering within the University. Then based on their received inputs, the questionnaire was slightly modified and eventually published online through a pre-selected service provider for online surveys.

Initially, the respondents were identified and selected by using the aforesaid activity presented in section 5.2.2. Next, the survey link: *http://freeonlinesurveys.com/rendersurvey.asp?sid=enw4s5p0emndu1a495484* was sent to them via email. They were asked to rate the importance of each factor using the scale given in Table 5.2. The obtained responses effectively reached 62 responses. This response rate is considered adequate because the purpose of the survey was mainly to highlight the most important criteria so that the weakest factors can be ignored and possibly dropped from further analysis.

By referring to the respondents' profiles, it has been found that all of them are generally involved in telecommunications field, where some of them are particularly dealing with rural telecommunications projects. They can be categorised by their professional backgrounds into three categories as shown in Figure 5.1: Of the 62 respondents 20 (32.3%) of them are telecoms engineers, 33 (53.2%) are consultants and 9 (14.5%) are academics. This mix up of the respondents' expertise confirms their familiarity with the selection factors and indicates that they were very well placed to provide useful data for such a survey.

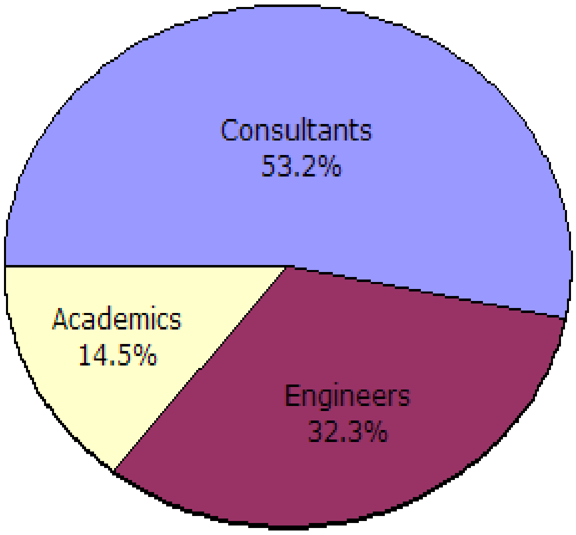


Figure 5.1 Categorisation of respondents by their professional background

The results obtained from the survey are tabulated as shown in Appendix C. They are analysed using SPSS package (SPSS Inc., 2006) and presented in this section with respect to the rating of the importance of the factors influencing the selection of rural telecommunication backbone infrastructure technology. As shown in Table 5.2, five qualitatively different categories with five corresponding numerical figures were used in the survey. The respondents were asked to rate the selection factors by choosing one of the categories which best represent their judgements. As there is no smooth transition from one category to the next, i.e. fractional values are not possible, therefore, they are considered discrete data as opposed to continuous data (Tabachnick & Fidell, 2001), and before getting involved in further analysis, one has to resolve issues of missing data values usually found in such survey data.

The survey results were stored in a data file, which initially was visually inspected and proofread against the original data. Then, an examination of descriptive statistics and graphic representation of the variables (criteria) was conducted. To facilitate the use of a software package, all criteria have been labelled from A1 to A31. Missing data points in the survey results is a pervasive problem in data analysis that needs to be carefully examined. Cases with missing values which are systematically different from cases without missing values can obscure the results. In addition, missing data may reduce the precision of calculated statistics because there is less information than originally planned. Another concern is that the assumptions behind many statistical procedures are based on complete cases, and missing values can complicate the theory required.

Assuming that some selection criteria included in the questionnaire might not be relevant to some respondents, accordingly an instruction was incorporated beforehand in the survey to inform respondents to skip any scale from marking if its particular factor was not of relevance to his/her expertise. This process created a disparity among the number of respondents (the total number of respondents is 62), as can be seen from Table 5.3 under the N titled row. This requires an adjustment of unequal sample size. SPSS MVA (Missing Values Analysis: SPSS Inc., 2006) helps to address several concerns caused by incomplete data values. It has been used to deal with this issue because it is specifically designed to highlight patterns of missing data points as well as to replace them in the data set. Table 5.3 shows SPSS output for the 18 selection criteria identified to contain missing data.

Table 5.3 Criteria with missing data points

Criteria		A1	A21	A24	A25	A30	A5	A6	A12	A14	A22	A23	A26	A10	A18	A28	A16	A29	A7
N		61	61	61	61	61	60	60	60	60	60	60	60	59	59	58	57	57	56
Missing	#	1	1	1	1	1	2	2	2	2	2	2	2	3	3	4	5	5	6
	%	1.6	1.6	1.6	1.6	1.6	3.2	3.2	3.2	3.2	3.2	3.2	3.2	4.8	4.8	6.5	8.1	8.1	9.7

The seriousness of missing data depends on its pattern; how much are missing? And why are they missing? The pattern of missing data is more important than the amount missing. If however, 5% or more data points are missing in a random pattern from a small to moderately sized data set, the problem needs to be carefully investigated (Tabachnick & Fidell, 2001). Table 5.4 depicts the missing data values from the 18 criteria arranged in ascending order with respect to each particular respondent. They are individually indicated by an (S) and are scattered throughout respondents and criteria. Since knowing why a data value is missing gives very useful information, the decision about how to handle missing data is also crucial. For example, are data missing because a respondent failed to respond or because that particular question did not apply to that individual? Therefore, by examining the pattern in Table 5.4, it is obvious that data values are missing randomly and are mainly due to a particular criterion being irrelevant to the respondent's expertise.

To verify that finding, i.e. to check whether the missingness of data points is not related to any other criteria, one can use the information at hand to test for patterns in missing data. A t-test can be performed for criteria which have at least 5% of data missing (A28, A16, A29 and A7), with $\alpha = 0.05$. However, since the displayed and tabulated patterns of missing data are found to be random, one can assume that the missingness of data points in a specific criterion is not related to any other criterion, i.e. randomly-based distribution of missing values.

Table 5.4 Missing patterns (criteria with missing values)

Respondents	Missing		Criteria																	
	#	%	A1	A21	A24	A25	A30	A5	A6	A12	A14	A22	A23	A26	A10	A18	A28	A16	A29	A7
5	1	3.2												S						
9	1	3.2	S																	
12	2	6.5					S												S	
15	4	12.9													S		S		S	S
17	2	6.5						S	S											
18	1	3.2										S								
23	1	3.2									S									
27	1	3.2																		S
28	2	6.5									S								S	
29	7	22.6								S		S			S	S	S	S		S
31	1	3.2																S		
37	2	6.5																S		S
38	4	12.9														S	S	S	S	
39	5	16.1														S	S	S	S	S
40	1	3.2								S										
43	1	3.2						S												
47	5	16.1			S	S							S	S						S
48	1	3.2											S							
49	1	3.2													S					
50	1	3.2							S											
55	1	3.2		S																

S → Indicates missing data point

There are a number of statistical methods that can be used to deal with missing data values; among them is to use Mean substitution for the missing values (Tabachnick & Fidell, 2001). This method has been adopted to handle this issue because it is a popular way to estimate missing values. Means are calculated for each criterion from available data and used to replace missing values for that criterion prior to analysis. For instance, Funding criterion is missing one data value; the Mean value for Funding is computed and inserted in place of the missing value. The Mean is considered an appropriate guess about the missing value in each criterion because the proportion of missing values is relatively small. SPSS has been used to generate univariate descriptive statistics shown in Table 5.5. Then, all criteria have been sorted in descending order according to their Mean values, which also represents the relative importance index of the criteria.

As aforementioned, given that discrete data sets take on a limited and usually small number of values, a respondent of this survey has no other option but to select a number from 1 to 5 to represent his judgement. In other words, a respondent has not been asked for random numerical estimates and given a free hand to any numbers he can choose. Therefore, as indicated in columns headed Minimum and Maximum in Table 5.5, there is no possibility to find 'out of range' outliers in this data set.

Table 5.5 Descriptive statistics of the survey results

Criteria	N	Min	Max	Mean	Criteria	N	Min	Max	Mean
A3 Operating cost	62	2	5	4.13	A9 Flexibility	62	2	5	3.52
A1 Funding sources	62	1	5	4.11	A30 Licensing constraints	62	1	5	3.52
A8 Reliability	62	2	5	4.00	A24 Population density	62	1	5	3.48
A2 Capital cost	62	2	5	3.98	A26 Community ~ interest	62	1	5	3.42
A13 Ease ~ maintenance	62	1	5	3.94	A22 Proposed usage	62	1	5	3.40
A14 Remote ~ manage.	62	1	5	3.88	A15 Avail ~ technicians	62	1	5	3.34
A11 Compatibility	62	2	5	3.81	A5 Economic ~ area	62	1	5	3.32
A21 Coverage range	62	1	5	3.80	A23 Existing ~ infrastruc.	62	1	5	3.32
A25 Demand	62	1	5	3.77	A7 Latency	62	1	5	3.30
A28 Spectrum	62	1	5	3.74	A29 Rights of way	62	1	5	3.30
A27 Affordability	62	2	5	3.73	A20 Remoteness of area	62	1	5	3.26
A31 Security ~ infrastruc.	62	1	5	3.73	A18 Terrain topography	62	1	5	3.24
A12 Ease of installation	62	1	5	3.72	A16 Rollout time	62	1	5	3.11
A4 Return ~ investment	62	1	5	3.63	A19 Climatic conditions	62	1	5	3.00
A10 Scalability	62	1	5	3.54	A17 Parallel infrastructure	62	1	5	2.97
A6 Bandwidth	62	1	5	3.53					

In an attempt to make the network structure more manageable, the author has explored the possibility of reducing the number of criteria by dropping the least important criteria or merging some of them together. This is in order to avoid the presence of too many criteria which will later make the pairwise comparisons in evaluating infrastructure technologies a difficult and time consuming process. However, based on the survey results in percentages that are graphically summarised in Figure 5.2, one can observe that all criteria are mostly within two categories, namely strongly important and very strongly important.

The only exception is the result of the 'operating cost' criterion which is inclined more towards the extremely important grade. Furthermore, a cut-off value method has been investigated to reduce the number of criteria. By taking the average of the highest 4.13 (see Table 5.5) and the lowest 2.97 mean rating values of all factors included in the survey, the cut-off point can be calculated, which is found to be equal to 3.55. Then, by setting this cut-off point in Table 5.5, one can find out that seventeen criteria with mean values less than the cut-off point could be ignored. As such an outcome will not be justified because the selection problem then will not be addressed properly, it was therefore, decided to keep and consider all criteria for further analysis.

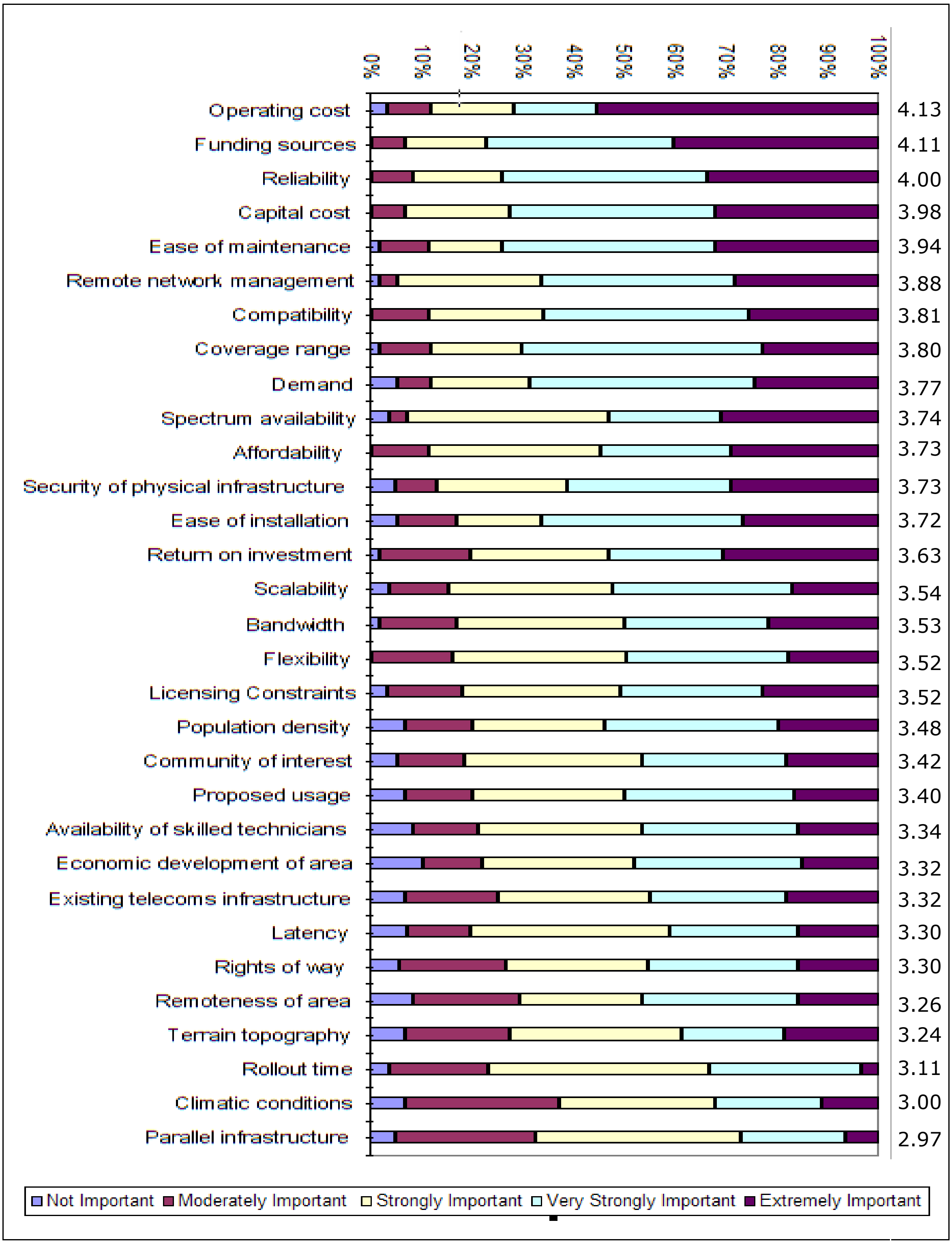


Figure 5.2 A graphical representation of the online survey results in percentages

5.4 Grouping of the criteria into clusters

The ANP model consists of clusters of elements connected by their dependence to one another. A cluster allows one to think about grouping criteria that share a set of attributes (Saaty, 2005). The model therefore is designed by grouping the factors contributing to providing a solution into clusters. The criteria are thus meaningfully grouped and assigned into six clusters according to relevance. They were clustered so that each cluster only includes criteria that are comparable or do not differ by orders of magnitude. In other words, items of very small significance were not included in the same cluster as items of greater significance. This is to ensure clustering the more important criteria together and the less important criteria together.

The criteria relative importance index (Mean rating value) is used as a reference as can be seen in Table 5.6. Moreover, in order to model the problem correctly and efficiently, there is a need to limit the number of criteria within each cluster to between seven to nine criteria, so that not more than nine criteria are grouped within each particular cluster. This is because experiments have shown that it is cognitively challenging for human beings to deal with more than nine factors at one time and this can result in less accurate priorities (Saaty, 2005). In addition, placing a large number of criteria in each cluster will lead to a massive increase in the number of the required pairwise comparisons. This will make the computation process difficult and sometimes infeasible.

Table 5.6 Ordering and clustering of criteria

Cluster	Criteria	Mean	Cluster	Criteria	Mean
A Technical	**A1** Reliability	4.00	C Economic	**C1** Operating cost	4.13
	A2 Ease of maintenance	3.94		**C2** Funding sources	4.11
	A3 Remote ~ management	3.88		**C3** Capital cost	3.98
	A4 Compatibility	3.81		**C4** Return on investment	3.63
	A5 Ease of installation	3.72		**C5** Economic ~ of area	3.32
	A6 Scalability	3.54	D Social	**D1** Demand	3.77
	A7 Bandwidth	3.53		**D2** Affordability	3.73
	A8 Flexibility	3.52		**D3** Population density	3.48
	A9 Latency	3.30		**D4** Community of interest	3.42
B Infrastructure	**B1** Coverage range	3.80	E Reg.	**E1** Spectrum availability	3.74
	B2 Security ~ infrastructure	3.73		**E2** Licensing constraints	3.52
	B3 Proposed usage	3.40		**E3** Rights of way	3.30
	B4 Availability ~ technicians	3.34	F Env.	**F1** Terrain topography	3.24
	B5 Access to ~ infrastructure	3.32		**F2** Climatic conditions	3.00
	B6 Remoteness of area	3.26		-	
	B7 Rollout time	3.11			
	B8 Parallel infrastructure	2.97			

All clusters are coded A through F, in this order: Technical (A), Infrastructure (B), Economic (C), Social (D), Regulatory (E), and Environmental (F). The elements in them are numbered starting with the cluster code; e.g. Reliability (A1), Ease of maintenance (A2), Remote network management (A3), Compatibility (A4) and so on. Similar decomposition processes have been performed on all other remaining clusters.

A description of each of these clusters and the elements that constitute them, which were considered as key criteria for this study is given in Appendix A.

5.5 Selection and classification of specific rural technologies

This section will overview telecommunications infrastructure technologies in the context of how it can be deployed in rural areas. It will cover some of the main technologies and examine the issues around them. The focus is on the technologies that can provide an adequate telecommunications backbone infrastructure in rural areas. There are several choices of technologies available nowadays to be applied to remote areas depending on the surrounding conditions of those areas. However, based on the published information, it has been found that the uniqueness of rural areas in developing countries makes it impractical to find a technology that will provide the optimum solution to all areas.

The activities abovementioned in section 5.2 have been used to identify potential technology alternatives. The published literature e.g. Kawasumi (2007), identified four technological solutions to provide rural backbone infrastructure that include two wireline technologies: Fibre Optic Cable and Power Line Communication and two wireless technologies: Fixed Wireless and Satellite Communication to provide e-services for rural and remote areas of developing countries. These technologies were initially highlighted as potential decision alternatives for this research.

To get feedback from people on feasible infrastructure technologies for rural areas, the following question was addressed to rural telecommunication experts and was published online in the LinkedIn forum: What are the latest 'up-to-date' broadband infrastructures (backbone & last-mile) needed to deploy e-services applications in rural areas of developing countries? Can anyone confirm, add, delete or improve the following:

For Backbone	**For Last-mile**
Fibre Optic Cable	Multipoint Microwave Distribution System- MMDS
Power Line Communication	Local Multipoint Distribution System- LMDS
Satellite Communication	802.11 B/G - WiFi
Microwave Link-P2P Fixed Wireless	802.16 - WiMAX

The question's link is:

- *(http://www.linkedin.com/answers/technology/informationtechnology/telecommunications/TCH_ITS_TCI/244156-25439845?browseIdx=3&sik=1228218782522&goback=%2Eamq)*

The purpose of posting such a question is to identify relevant technology alternatives currently available on the market, being offered all around the world based on real expert opinions. Within a period of one week, seven experts had positively responded with their opinions and contributions. Most of the inputs are considered very relevant to the subject matter, in which four technology alternatives have been selected for the model. Although the model is applicable with any number of technologies, for the sake of this research, the inclusion or omission of any specific technology (ies) does not imply any judgement, either positive or negative, on the part of the author.

The alternatives are composed of four traditional backbone infrastructure technologies, namely Fibre Optic Cable, Power Line Communication, Microwave Links and Satellite Communications. These possible technological solutions were then grouped and assigned into a cluster coded G. Its elements are numbered G1 'Fibre Optic Cable', G2 'Power Line Communication', G3 'Microwave Links' and G4 'Satellite Communications'. A brief description of the alternative cluster as well as the technological options that were considered as key technology options, capable of providing telecommunications backbone infrastructure for rural areas is given in Appendix A. Table 5.7 below will briefly compare some features of these infrastructural options.

Table 5.7 Telecommunications infrastructure suitability

Technology	Advantage	Disadvantage
Fibre optic cable	High speed High reliability High flexibility	High cost Long rollout time Most difficult to deploy
Power line communication	Simplicity & low cost Use of power lines High speed	Less reliability Data signal disruption Noise and interference
Microwave link	High reliability Low cost equipment Fast deployment	Low reach and line of sight Licensing constraints Less bandwidth and flexibility
Satellite communication	Coverage Ease of deployment Overcomes topography	Latency High cost Limited bandwidth

5.6 Conclusion

Following from this and the preceding chapters, several factors that explicitly consider many of the technology selection issues in rural areas are used to develop the decision model. As said earlier, there is a need to consider social, environmental, economic, regulatory, cultural and technical issues before deciding on a specific rural telecommunications technology. Two activities including an intensive literature review and consulting knowledgeable telecommunications personnel were used as means to consolidate the final list of selection criteria.

An online survey questionnaire was then conducted to rank the adopted criteria according to their importance from a perspective of telecommunication experts. The obtained responses effectively reached 62 responses, which is considered adequate because the purpose of the survey was mainly to highlight the most important criteria so that the weakest factors can be ignored and possibly dropped from further analysis. The respondents are generally involved in telecommunications field, where some of them are particularly dealing with rural telecommunications projects. The respondents' expertise showed: 32.3% telecoms engineers, 53.2% consultants and 14.5% academics.

The results obtained from the survey were tabulated and analysed using SPSS. Then, issues related to missing data values usually found in such survey data were treated. The Mean substitution method for the missing values was adopted to handle this issue because it is a popular way to estimate missing values. Means are calculated for each criterion from available data and used to replace missing values for that criterion prior to analysis. SPSS was used to generate univariate descriptive statistics, in which all criteria were sorted in descending order according to their Mean values, which also represents the relative importance index of the criteria. A graphic representation of the variables (criteria) was eventually conducted. The results showed that all criteria are mostly within two categories, namely strongly important and very strongly important. The only exception is the 'operating cost' criterion, which is inclined more towards the extremely important grade.

The next stage was grouping the criteria contributing to providing a solution into clusters according to relevance. The criteria were thus meaningfully assigned into six clusters, so that each cluster only includes criteria that are comparable or do not differ by orders of magnitude, limiting the number of criteria within each cluster to nine criteria. In order to ensure clustering the more important criteria together and the less important criteria together, the criteria relative importance index (Mean rating value) was used as a reference, and items of very small significance were not included in the same cluster as items of greater significance. Clusters were coded A through F, e.g. Technical (A), Infrastructure (B), etc., and the elements in them were numbered starting with the cluster code; e.g. Reliability (A1), Ease of maintenance (A2), and so on.

In this chapter, it was shown that there are a number of infrastructural options and different means of delivering advanced telecommunications services to rural users. Hence, using the same means, which were implemented for the criteria identification, four telecommunications infrastructure technologies capable of providing connectivity to rural areas were highlighted and adopted for this study, namely Fibre Optic Cable, Power Line Communication, Microwave Links and Satellite Communications. These possible solutions were then grouped, assigned into a cluster G and coded G1 'Fibre Optic Cable', G2 'Power Line Communication', G3 'Microwave Links' and G4 'Satellite Communications'.

A brief comparison of these technology options, deemed capable of providing telecommunications backbone infrastructure for rural areas, revealed that while fibre optic provides infinite bandwidth and high speed, it is also the most difficult option to deploy in rural areas. Simplicity and low cost characterises power lines, but noise and interference are more dominant in such an alternative. Microwave technology is the most reliable in rural areas, but offers low reach and needs line of sight. Satellite incurs high bandwidth expenses and high latency, but it is easy to deploy in remote rural areas and offers very wide coverage.

6. FORMULATION AND ESTIMATION OF THE AHP/ANP MODELS

6.1 Introduction

The analytic hierarchy/network processes (AHP/ANP) modelling processes are one of the mathematical methods used for solving multicriteria decision problems. Both are based on a general measurement theory that combines certain concepts from mathematics and psychology fields. The AHP/ANP have been widely applied to a wide range of decision problems and extensive literature covers their applications in solving diverse and sophisticated problems. Their applications can be roughly grouped into the following areas: selection, evaluation, risk assessment, conflict analysis, modelling, budgeting, planning and development, etc. (Vaidya and Kumar, 2006). This classification is not intended to be exhaustive. However, since the decisions involved in rural settings are of complex nature, with some aspects compounded by the presence of intangible criteria. Hence, a suitable approach is needed that can produce effective solutions.

This research is focusing on rural telecommunications infrastructure selection using the ANP. The literature review on AHP/ANP applications given in Chapter 3 indicated that there is notable research in telecommunications, communication networks and internet access technologies. Yet, AHP/ANP applications in the selection of rural telecommunication infrastructure have not been found in the literature. This chapter therefore describes the formulation of generic AHP and ANP models for the selection of the rural telecommunications infrastructure that can be used to solve such selection problems. The four main phases including: structuring of the decision problem, measurement and data collection, determination of normalised weights and synthesis – finding solution to the problem are described.

As the title of this chapter implies, there are two types of structures. The first part of this chapter covers a discussion of the AHP model, in which a hierarchical decision scheme is constructed by way of dividing the problem into decision elements comprised of: the main goal, which is placed at the top of the hierarchy, criteria and subcriteria in the middle and then the alternatives at the bottom. Each particular element is pairwise compared with respect to its parent element by means of real data obtained from telecoms experts. Each phase is explained to illustrate how to develop the AHP model, demonstrate how it could be used to prioritise the four adopted technology alternatives and facilitate and accelerate the selection process.

The second part of this chapter provides an in-depth discussion of the network model, in which a decision scheme is developed to model the same problem demonstrating the suitability of the ANP to enhance the selection process. The ANP model is also developed based on concerned experts' views of relevant selection criteria and potential technology alternatives. An explanation of the development of the network structure is given, identifying all possible dependencies and interactions among criteria and alternatives. This task is completed by seeking inputs from telecoms experts through another survey questionnaire, which is conducted for this purpose. Pairwise comparisons, which are conducted using two questionnaire types, web-based and text-type, are presented. Supermatrices are created and the synthesis of the results is finally performed using the *SuperDecisions*. A concluding summary is given at the end of this chapter.

6.2 Formulation and estimation of the AHP model

In this section, an AHP model will be developed to show how this method can be used to model a problem in the rural telecommunications environment. As each telecoms infrastructure provider may have its own set of criteria, thus, the aim here is to present a generic model based on factors and alternatives identified from the published literature, best practices and telecommunications experts (as described in chapter 5). The model could then be adapted or extended to support a particular context or a situation of a developing country. Planners may therefore augment this model with their own company-specific factors that might change the priorities.

6.2.1 Structuring the rural telecommunications infrastructure selection problem

In order to adapt the AHP methodology for such a technology selection task, the first step is to arrange the elements of the decision problem in the form of a hierarchy. A top down approach has been adopted in formulating the AHP model for this research. A hierarchy that consists of four levels, and descends from the general to the more particular was developed as shown in Figure 6.1. The top level is the overall goal of the decision, followed by the decision criteria which impact the goal directly in the second level. The subcriteria level comes next against the alternatives to be evaluated at the lowest level.

The goal of this decision problem is the selection of backbone infrastructure technology to provide quality telecommunications services to rural areas. The objectives of such a selection task are the enhancement of telecommunications access through the expansion of the connectivity to rural and remote areas, offer telecommunications services that can meet customer requirements, and increase the return on investments. These objectives can be achieved by considering six strategic criteria, namely technical, infrastructure, economic, social, regulatory and environmental, pertaining to rural telecommunications infrastructure, which form the second level in the hierarchy. The third level of the hierarchy contains the subcriteria which were already determined in chapter 5. They are expanded from the upper strategic criteria level and are grouped in the second level under the six criteria as shown in Figure 6.1.

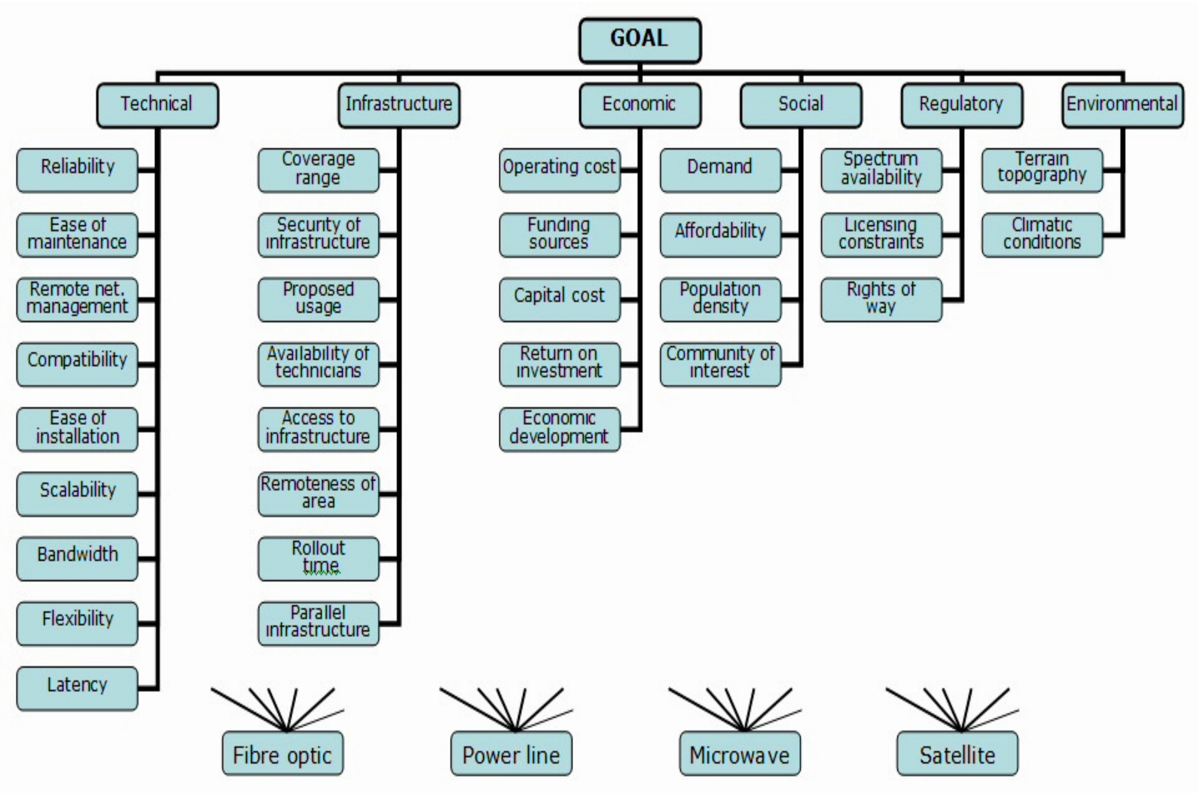


Figure 6.1 AHP hierarchy for rural telecoms backbone infrastructure selection

The criteria and subcriteria used in the hierarchy can be assessed using the AHP approach of pairwise comparison of elements in each level with respect to every parent element located one level above. Local priorities result directly from pairwise comparisons of the subcriteria with respect to the criteria, while global priorities result from the multiplication of criteria and subcriteria priorities. For instance, a set of global priority weights is produced for each of the subcriteria by multiplying local weights of the subcriteria with weights of all the parent elements above it. The local priorities define a share of a given decision-making element in reaching the goal at the upper level, where the global priorities of a given level represent in turn the share of each element in reaching the main goal, which is the selection of telecoms backbone technology for rural areas.

The lowest level of the hierarchy is the alternatives which include different technologies for selection as described in Appendix A. In applying the AHP model to a real case study, any number of potential technologies can be included. However, it will be more effective if only a few major candidates are shortlisted for selection. The AHP hierarchical structure allows for dependencies among elements to be only between the levels of the hierarchy, and the only possible direction of impact is towards the top of the hierarchy. Also, the elements of a given level are assumed to be mutually independent, and the possibility of including feedback relationships in the model is eliminated. The overall weighting of a technology is generated by adding the global priorities of all elements in the hierarchy.

6.2.2 Measurement and data collection – pairwise comparisons

After building the hierarchy, next is the pairwise comparisons phase. It is one of the major strengths of the AHP. It derives accurate ratio scale priorities as opposed to using traditional approaches of assigning weights which can also be difficult to justify. The pairwise comparison matrices were devised from the hierarchy shown in Figure 6.1, from the goal level down to the alternative level. The lines connecting the goal to each criterion mean that the criteria must be pairwise compared for their importance with respect to the goal. Similarly, the lines connecting each criterion to the subcriteria mean the latter are pairwise compared for their importance with respect to the criterion itself. Finally, the lines connecting each subcriterion to the alternatives mean the alternatives are pairwise compared as to which is more important for that criterion. Hence, from the hierarchy shown in Figure 6.1, there are 38 sets of pairwise comparison matrices, 1 for the criteria with respect to the goal, 6 for the subcriteria with respect to each criterion, and 31 for the alternatives with respect to each of the 31 subcriteria.

The questionnaires used to collect the data are shown in Appendix G. The experts were asked to fill them in using numbers from the fundamental scale to represent their judgements: 1 = equal, 3= moderately dominant, 5 = strongly dominant, 7 = very strongly dominant and 9 = extremely dominant (Saaty, 2001). The collected results were then entered in a reciprocal matrix in order to form the corresponding pairwise comparison judgement matrices. It should be noted that the AHP requires less pairwise comparisons compared with the ANP. Therefore, part of the ANP pairwise comparisons results presented in Appendix H were utilised for this task. The next phase is to determine the normalised weights.

6.2.3 Determining the normalised weights

The pairwise comparison judgements were then combined using the geometric mean at each hierarchy level to arrive at consensus pairwise comparison judgement matrices as shown in Appendix D. Ratio scales are then derived from each matrix in the form of principal eigenvectors (Saaty, 2005) as described in Chapter 4, subsection 4.3.2.3. They are represented by the resultant normalised eigenvectors which include the unique local priorities, i.e. the relative importance of the elements on the same level of the hierarchy over an element of the next higher level with respect to a common attribute. In this chapter, the eigenvector method, which approximates the eigenvector of a reciprocal matrix, is used to estimate the local priority vectors as explained below. For the meaning of the eigenvectors and eigenvalues and how to compute them manually, one can refer to Saaty (2010).

As an example to illustrate the computation process of the local priorities, consider the reciprocal pairwise comparisons matrix of the Technical criterion's subcriteria shown in Table 6.1, in which all of the subcriteria A1 to A9 are compared with respect to their parent criterion A "Technical". Figure 6.2 depicts an *Excel* screenshot demonstrating how the normalised priority weights of each element were computed. The computation process was carried out by following three steps:

1. Sum all column values of the reciprocal matrix to get the column sum as shown in Table 6.1.

Table 6.1 Summing the column elements

A TECHNICAL	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**
A1 Reliability	1	1.22	2.91	3.23	1.82	6.05	0.98	4.90	9.67
A2 Ease of maintenance	0.82	1	1.27	5.34	3.68	4.33	1.00	6.96	2.91
A3 Remote ~ management	0.34	0.79	1	1.39	1.09	5.01	0.39	5.00	8.00
A4 Compatibility	0.31	0.19	0.72	1	0.56	1.19	0.35	1.19	7.00
A5 Ease of installation	0.55	0.27	0.92	1.79	1	2.87	0.45	8.74	6.70
A6 Scalability	0.17	0.23	0.20	0.84	0.35	1	0.18	1.79	2.01
A7 Bandwidth	1.02	1.00	2.59	2.86	2.23	5.68	1	3.06	5.06
A8 Flexibility	0.20	0.14	0.20	0.84	0.11	0.56	0.33	1	2.99
A9 Latency	0.10	0.34	0.13	0.14	0.15	0.50	0.20	0.33	1
∑	***4.51***	***5.18***	***9.94***	***17.43***	***10.99***	***27.19***	***4.88***	***32.97***	***45.34***

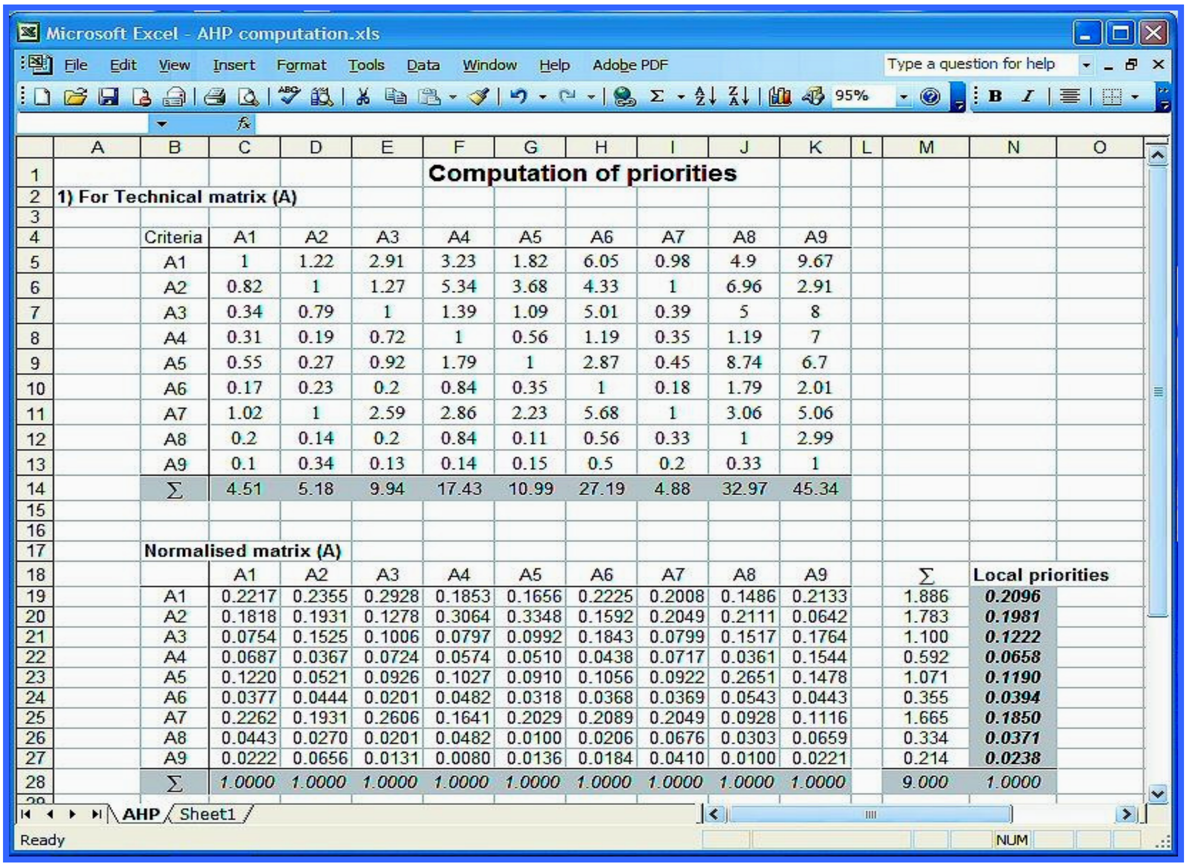
2. Divide the value of each element in the matrix by the column sum obtained in Table 6.1 to obtain the normalised relative weight. The resultant column sum is equal to 1 as shown in Table 6.2.

3. Work out the average across the rows elements in Table 6.2 to get the normalised principal eigenvector (also called priority vector) as shown in the most right column of Table 6.2.

Table 6.2 Priorities of subcriteria with respect to technical criterion

A	A1	A2	A3	A4	A5	A6	A7	A8	A9	Priorities
A1	0.2217	0.2355	0.2928	0.1853	0.1656	0.2225	0.2008	0.1486	0.2217	***0.2096***
A2	0.1818	0.1931	0.1278	0.3064	0.3348	0.1592	0.2049	0.2111	0.1818	***0.1981***
A3	0.0754	0.1525	0.1006	0.0797	0.0992	0.1843	0.0799	0.1517	0.0754	***0.1222***
A4	0.0687	0.0367	0.0724	0.0574	0.0510	0.0438	0.0717	0.0361	0.0687	***0.0658***
A5	0.1220	0.0521	0.0926	0.1027	0.0910	0.1056	0.0922	0.2651	0.1220	***0.1190***
A6	0.0377	0.0444	0.0201	0.0482	0.0318	0.0368	0.0369	0.0543	0.0377	***0.0394***
A7	0.2262	0.1931	0.2606	0.1641	0.2029	0.2089	0.2049	0.0928	0.2262	***0.1850***
A8	0.0443	0.0270	0.0201	0.0482	0.0100	0.0206	0.0676	0.0303	0.0443	***0.0371***
A9	0.0222	0.0656	0.0131	0.0080	0.0136	0.0184	0.0410	0.0100	0.0222	***0.0238***
∑	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	**1.0000**

Since it is normalised, the sum of all elements in the priority vector is equal to 1. The priority vector shows relative weights among the subcriteria that are compared. In the example above, the most important subcriteria are: A1 'Reliability', A2 'Ease of maintenance', and A7 'Bandwidth' with 20.96%, 19.81% and 18.50% respectively, i.e. the most preferable technical factors when selecting rural telecommunications backbone technology are reliability, followed by ease of maintenance and bandwidth. The remaining local priorities can be read directly from Table 6.2.



Computation of priorities

1) For Technical matrix (A)

Criteria	A1	A2	A3	A4	A5	A6	A7	A8	A9
A1	1	1.22	2.91	3.23	1.82	6.05	0.98	4.9	9.67
A2	0.82	1	1.27	5.34	3.68	4.33	1	6.96	2.91
A3	0.34	0.79	1	1.39	1.09	5.01	0.39	5	8
A4	0.31	0.19	0.72	1	0.56	1.19	0.35	1.19	7
A5	0.55	0.27	0.92	1.79	1	2.87	0.45	8.74	6.7
A6	0.17	0.23	0.2	0.84	0.35	1	0.18	1.79	2.01
A7	1.02	1	2.59	2.86	2.23	5.68	1	3.06	5.06
A8	0.2	0.14	0.2	0.84	0.11	0.56	0.33	1	2.99
A9	0.1	0.34	0.13	0.14	0.15	0.5	0.2	0.33	1
∑	4.51	5.18	9.94	17.43	10.99	27.19	4.88	32.97	45.34

Normalised matrix (A)

	A1	A2	A3	A4	A5	A6	A7	A8	A9	∑	Local priorities
A1	0.2217	0.2355	0.2928	0.1853	0.1656	0.2225	0.2008	0.1486	0.2133	1.886	***0.2096***
A2	0.1818	0.1931	0.1278	0.3064	0.3348	0.1592	0.2049	0.2111	0.0642	1.783	***0.1981***
A3	0.0754	0.1525	0.1006	0.0797	0.0992	0.1843	0.0799	0.1517	0.1764	1.100	***0.1222***
A4	0.0687	0.0367	0.0724	0.0574	0.0510	0.0438	0.0717	0.0361	0.1544	0.592	***0.0658***
A5	0.1220	0.0521	0.0926	0.1027	0.0910	0.1056	0.0922	0.2651	0.1478	1.071	***0.1190***
A6	0.0377	0.0444	0.0201	0.0482	0.0318	0.0368	0.0369	0.0543	0.0443	0.355	***0.0394***
A7	0.2262	0.1931	0.2606	0.1641	0.2029	0.2089	0.2049	0.0928	0.1116	1.665	***0.1850***
A8	0.0443	0.0270	0.0201	0.0482	0.0100	0.0206	0.0676	0.0303	0.0659	0.334	***0.0371***
A9	0.0222	0.0656	0.0131	0.0080	0.0136	0.0184	0.0410	0.0100	0.0221	0.214	***0.0238***
∑	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*9.000*	*1.0000*

Figure 6.2 An Excel screenshot of the computation of priorities

The relative weights are the ratio scales that allow one to divide among them. For example, from Table 6.2, one can see that the Reliability (A1) of a technology is 3.19 times (=0.2096/0.0658) more important than its Compatibility (A4) with other systems. Also, the Reliability is 8.81 (=0.2096/0.0238) times (i.e. extremely) more important than the Latency (A9). The normalised priority vectors of all judgement matrices were calculated and tabulated. The results of each matrix, and hence the corresponding element at each level, are shown in the rightmost column of each matrix as illustrated in Appendix D.

Aside from the priorities, one can check the consistency of the experts' judgements. The inconsistency measures the logical inconsistency of judgements, and it is useful for identifying possible errors in them. The computation and the meaning of consistency are already explained in Chapter 4, subsection 4.3.2.3.1, where Saaty (1980) suggested adopting the consistency index (CI) and consistency ratio (CR) to verify the consistency of the comparison matrix. Thus, in order to compute the CR, one needs what is called the principal eigenvalue $(\lambda_{\max})$, which is obtained from the summation of products between each element of the eigenvector and the sum of columns of the reciprocal matrix. For example, Tables 6.1 and 6.2 yield:

$$\lambda_{\max} = 4.51 * 0.2096 + 5.18 * 0.1981 + 9.94 * 0.1222 + ... + 45.34 * 0.0238 = 9.9172$$

And from Chapter 4, subsection: 4.3.2.3.1, recalling Equations 9 & 10 and for n = 9 (Table 4.2) yield: $CR = \frac{(\lambda_{\max} - n)/(n-1)}{RI} = \frac{(9.9172 - 9)/(9-1)}{1.45} = 0.0791$

The CR of each matrix was calculated as shown below the pairwise comparison matrices presented in Appendix D. It is clear that all matrices except one have a value of $\mathrm{CR} \le 0.1$. This implies that the experts were nearly consistent in their judgements. The matrix shown in Table D.1, i.e. aggregated pairwise judgement matrix for criteria with respect to the goal has a value of CR=0.1351. The entries of this matrix represent a group judgment that were taken from four different experts and were aggregated using the geometric mean. As shown under Table D.1 in Appendix D, the *SuperDecisions* can be used to highlight the most inconsistent entry in this matrix. The CR of the above matrix can then be improved by replacing the most inconsistent judgement in the matrix with a more consistent value.

6.2.4 Synthesis – finding a solution to the problem

The next phase of the process is to synthesise the overall solution, i.e. finding the global or composite normalised weights for the decision alternatives at the bottom level. Excel was used again to compute the overall priority of each alternative. The normalised priority weights of criteria and subcriteria obtained from the previous phase are combined together with all successive hierarchal levels. This is in order to obtain the global composite priority vector of unique and normalised weights for the entire hierarchy, which was obtained by multiplying the local priority weight of each element with the local weight of its parent element, i.e. from which it is connected. The resultant global priority vector for this model is shown in Table 6.3, which will be used to find the relative priorities of the alternatives.

Table 6.3 Composite priority weights for the criteria and subcriteria

Criteria	Local priorities	Subcriteria	Local priorities	Global priorities
Technical	0.2931	**A1** Reliability	0.2096	**0.0614**
		A2 Ease of maintenance	0.1981	**0.0581**
		A3 Remote ~ management	0.1222	**0.0358**
		A4 Compatibility	0.0658	**0.0193**
		A5 Ease of installation	0.1190	**0.0349**
		A6 Scalability	0.0394	**0.0115**
		A7 Bandwidth	0.1850	**0.0542**
		A8 Flexibility	0.0371	**0.0109**
		A9 Latency	0.0238	**0.0070**
Infrastructure	0.2473	**B1** Coverage	0.3719	**0.0920**
		B2 Security ~ infrastructure	0.0927	**0.0229**
		B3 Proposed usage	0.0252	**0.0062**
		B4 Availability ~ technicians	0.0637	**0.0158**
		B5 Access ~ infrastructure	0.0832	**0.0206**
		B6 Remoteness of area	0.1722	**0.0426**
		B7 Rollout time	0.0559	**0.0138**
		B8 Parallel infrastructure	0.1352	**0.0334**
Economic	0.2758	**C1** Operating cost	0.4160	**0.1147**
		C2 Funding	0.2310	**0.0637**
		C3 Capital cost	0.1448	**0.0399**
		C4 Return on investments	0.1261	**0.0348**
		C5 Economic develop ~ area	0.0821	**0.0226**
Social	0.0690	**D1** Demand	0.0404	**0.0028**
		D2 Affordability	0.1575	**0.0109**
		D3 Population density	0.2136	**0.0147**
		D4 Community of interest	0.5885	**0.0406**
Regulatory	0.0563	**E1** Spectrum	0.0716	**0.0040**
		E2 Licensing	0.2316	**0.0131**
		E3 Rights of way	0.6968	**0.0392**
Environmental	0.0584	**F1** Terrain topography	0.8415	**0.0491**
		F2 Climatic conditions	0.1585	**0.0093**
			$\sum$	**1.0000**

Once the global priorities of all subcriteria are obtained, they were multiplied by the local priority of each alternative with respect to each subcriterion to obtain the evaluation score (weight) of each alternative (see eq. (14) in chapter 4). Finally, an overall score for each alternative is obtained by summing each evaluation score column as shown in Table 6.4.

Table 6.4 Synthesized priorities for the alternatives

Criteria	Subcriteria	Global priorities	Alternatives							
			G1 Fibre	Evaluation score	G2 Power line	Evaluation score	G3 Microwave	Evaluation score	G4 Satellite	Evaluation score
A	A1	0.0614	0.5707	0.0350	0.0462	0.0028	0.2604	0.0160	0.1227	0.0075
	A2	0.0581	0.0841	0.0049	0.1126	0.0065	0.4935	0.0287	0.3098	0.0180
	A3	0.0358	0.1187	0.0042	0.0853	0.0031	0.2549	0.0091	0.5411	0.0194
	A4	0.0193	0.1586	0.0031	0.0568	0.0011	0.5594	0.0108	0.2253	0.0043
	A5	0.0349	0.1353	0.0047	0.0631	0.0022	0.2076	0.0072	0.5940	0.0207
	A6	0.0115	0.4310	0.0050	0.0573	0.0007	0.3899	0.0045	0.1219	0.0014
	A7	0.0542	0.5989	0.0325	0.0670	0.0036	0.2653	0.0144	0.0689	0.0037
	A8	0.0109	0.2041	0.0022	0.0575	0.0006	0.2881	0.0031	0.4503	0.0049
	A9	0.0070	0.4702	0.0033	0.3377	0.0024	0.1523	0.0011	0.0398	0.0003
B	B1	0.0920	0.0584	0.0054	0.0820	0.0075	0.2622	0.0241	0.5974	0.0550
	B2	0.0229	0.3900	0.0089	0.4369	0.0100	0.0996	0.0023	0.0735	0.0017
	B3	0.0062	0.4830	0.0030	0.3556	0.0022	0.0710	0.0004	0.0904	0.0006
	B4	0.0158	0.4704	0.0074	0.3781	0.0060	0.0546	0.0009	0.0969	0.0015
	B5	0.0206	0.0636	0.0013	0.0901	0.0019	0.5582	0.0115	0.2881	0.0059
	B6	0.0426	0.0525	0.0022	0.0709	0.0030	0.3183	0.0136	0.5583	0.0238
	B7	0.0138	0.4768	0.0066	0.3820	0.0053	0.0933	0.0013	0.0479	0.0007
	B8	0.0334	0.5332	0.0178	0.3117	0.0104	0.0880	0.0029	0.0671	0.0022
C	C1	0.1147	0.1376	0.0158	0.5254	0.0603	0.2097	0.0241	0.1273	0.0146
	C2	0.0637	0.1072	0.0068	0.0824	0.0052	0.4821	0.0307	0.3283	0.0209
	C3	0.0399	0.0490	0.0020	0.2446	0.0098	0.5343	0.0213	0.1721	0.0069
	C4	0.0348	0.0875	0.0030	0.1221	0.0042	0.6034	0.0210	0.1870	0.0065
	C5	0.0226	0.3075	0.0069	0.5044	0.0114	0.1208	0.0027	0.0673	0.0015
D	D1	0.0028	0.5536	0.0016	0.2742	0.0008	0.1205	0.0003	0.0517	0.0001
	D2	0.0109	0.0474	0.0005	0.0845	0.0009	0.5743	0.0063	0.2937	0.0032
	D3	0.0147	0.0660	0.0010	0.1068	0.0016	0.2363	0.0035	0.5909	0.0087
	D4	0.0406	0.0519	0.0021	0.2865	0.0116	0.0695	0.0028	0.5921	0.0240
E	E1	0.0040	0.0532	0.0002	0.0565	0.0002	0.3058	0.0012	0.5846	0.0023
	E2	0.0131	0.2920	0.0038	0.5170	0.0068	0.1280	0.0017	0.0629	0.0008
	E3	0.0392	0.5712	0.0224	0.3041	0.0119	0.0707	0.0028	0.0540	0.0021
F	F1	0.0491	0.0454	0.0022	0.0790	0.0039	0.2999	0.0147	0.5756	0.0283
	F2	0.0093	0.5296	0.0049	0.3126	0.0029	0.0971	0.0009	0.0608	0.0006
	$\sum$	1.0000		***0.2207***		***0.2008***		***0.2859***		***0.2921***

6.2.5 Analysis and discussion

The resulting priorities of the alternatives are illustrated in Table 6.5. From the Normalised column, Satellite technology is the most preferred alternative and has the highest score in this AHP model with a priority of 29.21%. Microwave comes next with a priority of 28.59% and then Fibre and Power line technologies with 22.07% and 20.08% respectively. The sum of the priorities in this column is equal to one. This complies with the AHP procedure and demonstrates that its steps are applied properly.

Table 6.5 Synthesized priorities for the alternatives

Alternatives	**Priorities**	
	Normalised	Idealised
G1 Fibre optic cable	0.2207	0.7556
G2 Power line communication	0.2008	0.6874
G3 Microwave links	0.2859	0.9788
G4 Satellite communication	0.2921	1.0000

The idealised column uses a normalisation by dividing the score of each alternative in the normalised column by the highest alternative score (0.2921). Hence, Satellite has a priority of 100%, the other priorities are in the same proportion as in the Normalised and so Microwave, Fibre optic cable and Power line are 97.88%, 75.56% and 68.74% respectively. Moreover, from Table 6.3, one can observe that the comparison of the criteria with respect to the goal yields that the technical criterion has the highest priority of 29.31%, expressing a certain advantage among others, which indicates more importance of the technical aspects in comparison to other economic, infrastructure, etc. factors.

The lowest priorities are for social, environmental and regulatory aspects with 6.90%, 5.84% and 5.63%, respectively. In Table 6.6, the subcriteria are arranged for ranking in a descending order of their global priorities. The table shows that the most important subcriterion among all is C1 'Operating cost' with a priority of 11.47% followed by B1 'Coverage' with 9.20% and C2 'Funding' with 6.37%. The top ten factors comprised a variety of subcriteria that belong to all criteria except the regulatory criterion. The least important subcriteria among others considered in the model with priorities of less than 1% are F1 'Climatic conditions', A9 'Latency', B3 'Proposed usage', E1 'Spectrum' and D1 'Demand' with 0.93, 0.70, 0.62, 0.40, and 0.28, respectively.

From the above analysis, one can observe that the AHP is capable of structuring the problem and providing a systematic approach to decision making. It allowed for diverse qualitative factors to be examined in a mathematical model, which can help to reduce the time needed to evaluate the alternatives. By using the traditional selection process in such problems, the decision may take months to be reached. As the criteria are clearly defined and the problem is structured systematically, the AHP allows the decision makers to visualise the strengths and weaknesses of each technology alternative by comparing their scores against each factor.

Table 6.6 The ranking of factors according to their global priorities

Rank	Subcriteria	Global priorities (%)
1	C1 Operating cost	11.47
2	B1 Coverage	9.20
3	C2 Funding	6.37
4	A1 Reliability	6.14
5	A2 Ease of maintenance	5.81
6	A7 Bandwidth	5.42
7	F1 Terrain topography	4.91
8	B6 Remoteness of area	4.26
9	D4 Community of interest	4.06
10	C3 Capital cost	3.99
11	E3 Rights of way	3.92
12	A3 Remote network management	3.58
13	A5 Ease of installation	3.49
14	C4 Return on investments	3.48
15	B8 Parallel infrastructure	3.34
16	B2 Security of physical infrastructure	2.29
17	C5 Economic development of area	2.26
18	B5 Access to existing telecoms infrastructure	2.06
19	A4 Compatibility	1.93
20	B4 Availability of skilled technicians	1.58
21	D3 Population density	1.47
22	B7 Rollout time	1.38
23	E2 Licensing	1.31
24	A6 Scalability	1.15
25	A8 Flexibility	1.09
26	D2 Affordability	1.09
27	F2 Climatic conditions	0.93
28	A9 Latency	0.70
29	B3 Proposed usage	0.62
30	E1 Spectrum	0.40
31	D1 Demand	0.28

The obtained final scores (weights) provide information (to contemplate explicit or implicit knowledge) about the alternatives and the way they are used to satisfy the selected factors, as well as the importance of these factors in order to reach the goal of the model. Taking this into consideration, a result where one can affirm which alternative is more preferable from telecoms experts' point of view is reached. However, the priority scores of the four technologies are actually quite close to each other and although Satellite technology achieved the highest score, it is only above Microwave's score by less than 1%. Also, Fibre optic's score is just less than 2% higher than that of Power lines. Hence, it becomes questionable for the decision makers to arrive at a consensus decision to select either of the alternatives. This outcome implies that while the AHP method has been studied extensively and used in numerous MCDM applications. However, the simplicity of the hierarchical structure and linear unidirectional hierarchical relationship among criteria and subcriteria in the AHP method hide important issues, such as interdependence among qualitative factors and interaction among decision making levels and so oversimplified the problem.

In AHP, a hierarchy considers the distribution of a property (goal) amongst the element being compared and judges which element has a greater influence on that property. The author believes that there is recognition that better ways of defining interactions are needed; the AHP is limited, as most interactions are currently identified by reducing them to pairwise sets between factors at the same level of the hierarchy. Whereas in actuality, in general, and specifically in rural telecommunications decision problems, functionality or purpose emerges from multiple interactions that thread their way through the system. Thus, there is a need for a holistic approach in which all the criteria and alternatives involved are connected in a network system that accepts various dependencies and interactions. Thus, such problems which are of complex nature, with some aspects compounded by the presence of intangible criteria cannot be structured hierarchically because they involve many interactions and dependencies requiring a MCDM method that can holistically deal with qualitative and quantitative data. Hence, the ANP model presented in the next section can overcome the shortcomings of the strict hierarchical structure inherited in AHP.

The ANP can deal with problems having complex relationships among criteria (dependency and feedback) and so it is considered more pragmatic approach to decision making which gives better predictions. The existence of feedbacks in any structure prevents the problem from being modelled hierarchically due to the difficulty in deciding which cluster is higher/lower than the other. Moreover, because of inner dependence, the relationships between the criteria of the same level are not represented hierarchically. Accordingly, based on the above and due to its holistic approach; the ANP is chosen as a dominant methodology for this study.

6.3 Formulation and estimation of the ANP model

In the following sections, the ANP will be used to model the same problem. It is chosen because it has some additional advantages over the AHP and other MCDM methods, in which all the elements involved are laid out in advance in a network system that allows for dependency and feedback.

6.3.1 Identifying dependencies among criteria

When a decision is to be made, there is a need to look at all the potential influences in the network structure (Saaty, 2005). Hence, to identify dependencies within the structure, one has to understand both the functional dependence among the elements being compared and their attributes/criteria and the structural dependence which is concerned with the manner in which they are related. These concepts are central in the ANP because in a network structure any element can depend on any other element, so that one not only asks which of two alternatives is more dominant with respect to a criterion, but also which of two criteria is more dominant with respect to an alternative (Saaty, 2005). The establishment of functional relationships among technology selection criteria is very tedious. Thus, for the purpose of this research, the presence and extent of dependency are derived from telecommunications experts' opinions and experiences, rather than on regression analysis of historical data which is often used to establish such relationships.

After structuring the decision problem, in which the clusters were identified and all the elements placed in their respective clusters, the next step is to examine the dominance of influence among criteria, in which one has to test for the mutual independence of criteria. The questions that need to be answered about the dominance of influence or the relative importance of influence are (Saaty, 2005): 1) Given a criterion, which of two elements is more dominant with respect to that criterion? 2) Which of two elements influences a third element more with respect to a criterion? In order to fulfil this task, a new survey questionnaire which included the dependency half-matrix shown in Table 6.7 was distributed to experts who were asked to fill in each cell that entails a comparative question to identify the dependency among each pair of criteria.

It was important in selecting the respondents to choose senior staff who, among them, had an overview of the research, were interested and actually involved in the field of rural telecommunications. This is because such a procedure can only be made by experts with long experience as well as special knowledge in the rural telecommunications field. The selected ten experts included three telecommunication academics (two telecoms professors and one research assistant), four telecoms engineers and three consultants. Initially, they were contacted by e-mail and asked to indicate any possible direct relationship between pairs of the row and column criteria using the scoring pattern shown in Table 6.8.

Table 6.7 The dominance of influence half-matrix

Criteria	A1	A2	A3	A4	A5	A6	A7	A8	A9	B1	B2	B3	B4	B5	B6	B7	B8	C1	C2	C3	C4	C5	D1	D2	D3	D4	E1	E2	E3	F1	F2
Reliability (A1)																															
Ease of maintenance (A2)																															
Remote network management (A3)																															
Compatibility (A4)																															
Ease of installation (A5)																															
Scalability (A6)																															
Bandwidth (A7)																															
Flexibility (A8)																															
Latency (A9)																															
Coverage range (B1)																															
Security of physical infrastructure (B2)																															
Proposed usage (B3)																															
Availability of skilled technicians (B4)																															
Access to existing telecoms infrastructure (B5)																															
Remoteness of area (B6)																															
Rollout time (B7)																															
Parallel infrastructure (B8)																															
Operating cost (C1)																															
Funding sources (C2)																															
Capital cost (C3)																															
Return on investment (C4)																															
Economic development of area (C5)																															
Demand (D1)																															
Affordability (D2)																															
Population density (D3)																															
Community of interest (D4)																															
Spectrum availability (E1)																															
Licensing constraints (E2)																															
Rights of way (E3)																															
Terrain topography (F1)																															
Climatic conditions (F2)																															

Scoring Pattern 0 = No Dependency 1 = Dependency Exists 2 = Inverted Dependency 3 = Mutual Dependency

Table 6.8 Scoring pattern for identifying dependency among criteria

Score	Relationship	Explanation
0	No Dependency	no relationship can be identified among criteria
1	Dependency Exists	row criteria depends on column criteria
2	Inverted Dependency	column criteria depends on row criteria
3	Mutual Dependency	column and row criteria depend on each other

To avoid any ambiguity in filling-in the half-matrix, the example below was also incorporated in the questionnaire:

Example: For the ‘Reliability criterion (A1):

- If a relationship can not be identified between reliability (A1) in the 1st row and ease of maintenance (A2) in the 2nd column, please write 0 in the corresponding cell A_1 $A_{2;}$
- If reliability depends on ease of maintenance, please write 1 in the equivalent cell;
- If ease of maintenance depends on reliability, please write 2 in the equivalent cell;
- If both criteria depend on each other, please write 3 in the corresponding cell.

Three out of the ten contacted people refrained from providing their inputs because they believed this task is a very lengthy and complex process. Hence, seven completed questionnaires were collected, i.e. a response rate of 70%. Expectedly, when the responses were analysed, some disparities among experts’ opinions were found. The majority rule was thus considered to aggregate the responses into a single matrix in accordance with the scale shown in Table 6.9. For example, 0% indicates that none of the experts acknowledged the existence of a relationship between any pair of criteria. Whereas, the values of 14%, 43% and 100% indicate that 1, 3 or 7 experts, respectively, confirmed that a relationship exists among any pairs of criteria.

Table 6.9 A scale used for the aggregation of dependency responses

No of experts	0	1	2	3	4	5	6	7
%	0	14	29	43	57	71	86	100

Table 6.10, shows the matrix entries represented by percentages to indicate the existence of a direct relationship from criterion i to criterion j, i.e. if criterion i depends on criterion j, then $14\% \le a_{ij} \le 100\%$. Zeros entries indicate no relationships were identified.

Table 6.10 Connections among elements of all clusters in percentages

		A1	A2	A3	A4	A5	A6	A7	A8	A9	B1	B2	B3	B4	B5	B6	B7	B8	C1	C2	C3	C4	C5	D1	D2	D3	D4	E1	E2	E3	F1	F2
A	A1	X	57	43	43	14	43	57	29	29	14	100	43	57	29	71	14	43	29	43	29	29	14	14	0	43	14	43	29	29	71	100
	A2	29	X	57	57	57	43	0	71	0	43	57	43	71	29	71	14	29	29	14	0	29	0	14	29	29	0	29	14	71	100	71
	A3	43	43	X	57	0	29	71	43	29	57	14	29	43	57	29	29	29	43	29	29	29	29	29	14	43	29	14	29	14	43	43
	A4	29	29	14	X	57	43	29	57	14	14	0	29	29	14	29	43	43	43	14	14	29	14	14	29	43	29	43	43	29	57	57
	A5	0	14	29	43	X	43	0	57	0	43	57	43	57	29	100	29	14	29	0	14	14	14	14	14	29	29	29	29	86	100	86
	A6	43	29	29	43	29	X	57	71	29	43	14	43	29	43	57	57	43	43	29	43	29	29	57	43	57	29	57	57	43	57	57
	A7	14	14	0	14	14	43	X	0	29	57	0	57	14	43	57	29	29	29	29	14	14	43	57	29	86	43	86	57	14	43	43
	A8	14	14	29	43	29	29	43	X	14	43	14	43	0	43	57	43	14	43	14	29	29	14	29	43	57	29	0	57	43	57	43
	A9	29	14	14	14	14	14	43	14	X	43	0	43	14	14	71	14	0	14	0	0	0	14	14	0	43	14	57	57	14	43	29
B	B1	43	14	14	14	29	14	14	14	29	X	14	43	14	57	100	29	57	14	29	29	57	71	57	29	86	71	86	100	43	100	43
	B2	14	14	14	14	14	14	14	14	14	29	X	43	29	14	86	0	29	29	0	14	14	57	0	0	43	29	14	29	43	57	29
	B3	57	14	14	43	14	14	43	43	57	43	43	X	57	29	57	29	29	29	29	14	29	57	43	86	57	57	57	86	29	57	29
	B4	29	43	29	14	29	0	0	14	0	0	0	0	X	14	71	43	14	14	14	29	0	43	29	14	29	29	14	14	14	14	14
	B5	14	14	0	43	14	14	14	14	14	14	14	14	29	X	86	43	71	43	29	43	43	57	14	29	29	14	43	43	71	43	43
	B6	29	14	14	0	0	0	0	14	14	14	14	0	29	29	X	29	0	29	14	29	29	43	29	29	57	57	43	29	29	71	71
	B7	29	0	29	29	43	0	14	0	0	43	43	14	71	29	71	X	43	14	29	29	29	43	71	29	86	29	86	57	86	86	86
	B8	14	29	29	14	29	29	29	14	14	29	29	14	14	43	71	29	X	14	14	43	14	71	29	14	14	0	14	14	29	43	29
C	C1	57	57	29	43	29	14	29	29	29	43	29	43	71	43	71	29	57	X	14	29	43	43	29	29	86	43	71	71	57	71	86
	C2	14	14	0	29	29	29	14	43	14	29	29	43	29	14	29	14	29	0	X	71	71	57	14	29	14	43	29	43	43	29	43
	C3	43	29	14	29	57	14	29	29	29	57	57	29	43	43	43	43	14	14	43	X	43	43	57	29	57	43	43	29	43	43	43
	C4	29	29	29	43	29	29	29	43	29	57	29	57	29	29	29	43	57	71	43	86	X	57	86	57	57	57	43	43	43	57	43
	C5	14	14	0	14	0	0	0	0	0	0	0	0	14	14	57	0	29	0	29	29	14	X	14	29	86	29	43	43	29	71	57
D	D1	71	14	0	29	29	0	57	29	14	43	14	71	0	43	57	0	0	29	29	14	29	43	X	57	57	29	43	14	29	29	43
	D2	29	29	29	29	29	0	29	14	29	14	29	29	0	14	14	0	14	43	29	43	43	43	43	X	29	57	57	29	43	29	14
	D3	14	14	0	0	0	14	14	0	0	29	0	0	14	0	43	0	43	14	14	14	29	14	43	14	X	43	29	14	14	57	57
	D4	14	14	0	0	0	0	0	0	14	0	0	29	0	14	29	0	29	0	14	14	43	29	43	29	29	X	43	14	43	29	14
E	E1	14	0	0	0	0	14	29	0	0	0	0	43	0	0	43	0	14	14	14	29	14	14	29	0	14	0	X	86	43	57	29
	E2	29	0	0	0	0	0	29	0	0	14	0	14	0	0	14	0	14	14	29	14	29	14	14	0	0	0	29	X	57	14	14
	E3	14	0	0	0	0	0	0	0	0	14	0	14	0	14	29	14	14	0	14	29	14	0	0	0	14	0	0	0	X	57	14
F	F1	14	0	0	0	0	0	0	0	0	14	0	0	0	0	29	14	0	0	14	29	14	14	0	0	14	0	0	0	0	X	14
	F2	14	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0	0	29	14	0	0	0	0	0	0	0	0	0	X

The results of the aggregation were then coded into a single zero-one matrix of criteria against criteria using a binary value of 1 to signify dependence of one criterion on another, and zero otherwise. A criterion need not depend on itself as. For example, an industry may not use its own output (Saaty, 2006). A majority condition of 4 out of 7 (4/7) experts' consensus (i.e. 57%) was considered as a minimum requirement for any entry that indicates the existence of a direct relationship between any pair of elements.

Table 6.11 shows all possible connections among all elements, where a_{ij} can take any of the following values:

- **0** → Indicates no relationship exists based on 7 experts' consensus;
- **0** → Indicates the entries have obtained < 4 experts' consensus; and
- **1** → Indicates the entries have obtained ≥ 4 experts' consensus.

The entries represented by 1s indicate the existence of a direct relationship from element i to element j, i.e. if i depends on j, then $a_{ij} = 1$. For each column of this matrix, a pairwise comparison matrix is constructed only for the dependent criteria. If a column is all zeros, then a zero vector is assigned to represent the priorities. In other words, the elements in the rows are evaluated with respect to the elements in the columns, i.e. the 1s in the columns will determine which elements in the rows are to be pairwise compared with respect to that column and a pairwise comparison matrix will only be constructed for the dependent element.

Table 6.11 The aggregated dependency matrix

Clusters	Criteria	with respect to																																		
		A1	A2	A3	A4	A5	A6	A7	A8	A9	B1	B2	B3	B4	B5	B6	B7	B8	C1	C2	C3	C4	C5	D1	D2	D3	D4	E1	E2	E3	F1	F2	G1	G2	G3	G4
A	A1	0	1	0	0	0	0	1	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
	A2	0	0	1	1	1	0	0	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	A3	0	0	0	1	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
	A4	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
	A5	0	0	0	0	0	0	0	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	A6	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0	1	0	1	1	0	1	1	1	1	1	1
	A7	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	1	0	1	0	1	1	0	0	0	1	1	1	1
	A8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	1	1	1	1
	A9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	1	1	1
B	B1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	1	1	1	0	1	1	1	1	0	1	0	1	1	1	1
	B2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	1	1	1
	B3	1	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	1	0	1	1	1	1	1	0	1	0	1	1	1	1
	B4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
	B5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	1	1	1
	B6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	1	1	1	1	1
	B7	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	1	0	1	1	1	1	1	1	1	1	1
	B8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1
C	C1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1	1	1	1
	C2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1
	C3	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	1	1	1
	C4	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	1	0	1	0	1	1	1	1	1	0	0	0	1	0	1	1	1	1
	C5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1	1	1	1
D	D1	1	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	1	1
	D2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1	1	1
	D3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
	D4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
E	E1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	1	1
	E2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1
	E3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1
F	F1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
	F2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
G	G1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
	G2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
	G3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
	G4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0

It should be noted that these connections determine the number of pairwise comparisons required to evaluate and assess the strength of the developed dependencies (influences) among elements, in terms of importance, preference or likelihood. In other words, after identifying all possible dependencies among criteria, as depicted in Table 6.11, the experts will be consulted to assess the strength of the developed dependencies by means of online questionnaires of the pairwise comparison questions, as will be discussed in the subsequent sections.

To further explain how these connections are translated into understandable terms, Table 6.11 illustrates the inner dependence, which is the influence of one element on another with respect to an attribute they have in common within a cluster. For example, in cluster A 'technical', column A8 means A2, A4, A5 and A6 are interrelated with respect to A8. Such connections imply that A2 'ease of maintenance', A4 'compatibility', A5 'ease of installation' and A6 'scalability' are to be pairwise compared with respect to A8 'flexibility'.

Moreover, the proposed model contains the outer dependence, which is the relationship between elements in a cluster with others in other clusters. For example, in Table 6.11, when considering A8 'flexibility', the elements G1 'Fibre optic cable', G2 'power line communication', G3 'microwave link' and G4 'satellite communication' in cluster G 'alternatives' are interconnected and so pairwise compared with respect to A8 in the technical cluster A. This is an outer dependence because elements are placed in different clusters.

In this technology selection model, which involves feedback links, the challenge is to determine the priorities of the elements in the network and in particular the alternatives. This is because the network model involves cycles connecting its components of elements, and cycling can be an infinite process, where the operations needed to derive the priorities become more demanding than has been normal with hierarchies. For instance, two telecoms technologies both can support broadband applications that need sufficient bandwidths, but the one which provides infinite bandwidth is also more costly when deployed in rural settings. The selection of either of the alternatives would lead a planner to choose the technology which provides unlimited bandwidth, but which is costly unless the criteria themselves are evaluated in terms of the technologies, and unlimited bandwidth criterion receives a smaller value and costs criterion a larger value. This is because both technologies are capable of supporting multimedia applications that require wider bandwidths.

Furthermore, in this model, G1 in Table 6.11 is the parent element and all elements in other clusters except in cluster G are its children elements, indicating that criteria can be compared with respect to an alternative. For instance, in addition to separately comparing

G1, G2, G3 and G4 with respect to each of A1 'reliability' and A7 'bandwidth', A1 and A7 must also be compared with respect to G1 'Fibre optic cable'. The question to be asked is: What is the more important characteristic of Fibre optic cable technology, its reliability or its bandwidth? These types of preference questions and answers in both directions help decision makers to establish true priorities for all the elements in the problem under investigation.

In this ANP model, there is a need to prioritize the influence of the clusters themselves on each other cluster to which the elements belong. This influence is assessed through paired comparisons with respect to a control criterion. The priority of each cluster is used to weight the priorities of all the elements in that cluster. This is to allow for feedback multiplication of priorities by other priorities in a cycle, an infinite number of times. The process would not converge unless the resulting matrix of priorities is column stochastic (each of its columns adds to one). Feedback, therefore, can improve the priorities derived from judgments and makes prediction more accurate.

Table 6.12 shows coloured representation of all possible relationships within the developed model. Recalling that 1 signifies dependence of one element on another, and zero otherwise; 'no dependencies' (i.e. grey-shaded clusters), indicate that the environmental cluster is the only cluster which is not dependent on any other cluster. Inner dependencies (i.e. yellow-shaded clusters) exist within all clusters, except for the environmental and alternatives clusters. Outer dependencies (i.e. white clusters) exist among several clusters, such as technical/infrastructure clusters, economic/social clusters, etc. Since feedback (i.e. light green-shaded clusters) exists in this network structure, it means there is mutual outer dependence of criteria in two different clusters as can be seen between the alternative cluster and all other clusters, technical/social clusters and infrastructure/economic clusters.

Based on the above analysis, it is obvious that the problem has inner dependencies, outer dependencies and feedback links developed among the elements in the network structure shown in Table 6.12, which excludes the hierarchy form and calls for the network form to model such a rural technology selection problem. Appendix E presents an introduction to the *SuperDecisions* software (Adams and Saaty, 2003) together with a brief description of its functions and modules such as design, computation, etc.

Table 6.12 Inner dependencies, outer dependencies and feedbacks within the structure

		A									B								C					D				E			F		G			
		A1	A2	A3	A4	A5	A6	A7	A8	A9	B1	B2	B3	B4	B5	B6	B7	B8	C1	C2	C3	C4	C5	D1	D2	D3	D4	E1	E2	E3	F1	F2	G1	G2	G3	G4
A	A1	0	1	0	0	0	0	1	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
	A2	0	0	1	1	1	0	0	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	A3	0	0	0	1	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
	A4	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
	A5	0	0	0	0	0	0	0	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	A6	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0	1	0	1	1	0	1	1	1	1	1	1
	A7	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	1	0	1	0	1	1	0	0	0	1	1	1	1
	A8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	1	1	1	1
	A9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	1	1	1
B	B1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	1	1	1	0	1	1	1	1	0	1	0	1	1	1	1
	B2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	1	1	1
	B3	1	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	1	0	1	1	1	1	1	0	1	0	1	1	1	1
	B4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
	B5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	1	1	1
	B6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	1	1	1	1	1
	B7	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	1	0	1	1	1	1	1	1	1	1	1
	B8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1
C	C1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1	1	1	1
	C2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1
	C3	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	1	1	1
	C4	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	1	0	1	0	1	1	1	1	1	0	0	0	1	0	1	1	1	1
	C5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1	1	1	1
D	D1	1	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	1	1
	D2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1	1	1
	D3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
	D4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
E	E1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	1	1
	E2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1
	E3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1
F	F1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	F2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G	G1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
	G2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
	G3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
	G4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0

→ No dependence → Inner dependence → Outer dependence → Feedback

SuperDecisions was used to construct the network model according to Table 6.11. It uses an arrow to signify dependence among elements and its direction starts from one element to another that may influence it (Saaty, 2005). An arrow is generated between clusters to represent outer dependence, while inner dependence is represented by attaching an arrow from a cluster to itself in the form of a 'loop', as can be seen from Figure 6.3. Two directional arrows show mutual outer dependence (feedback) among elements of the network to represent their relationships with each other.

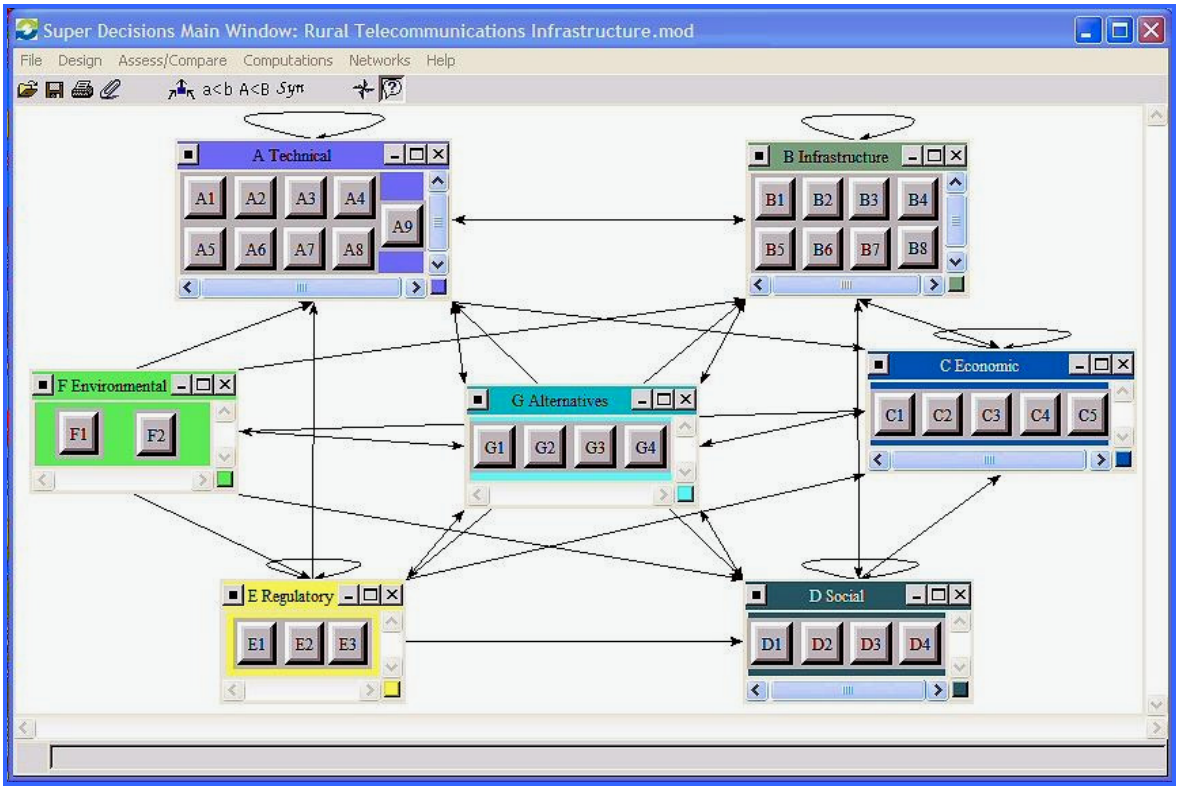


Figure 6.3 The ANP network model with connections among elements/clusters

This particular kind of relationships is not available in AHP models (Saaty, 2010). The connections between clusters are illustrated in Figure 6.3 in which the elements are represented by their codes. "A cluster is connected to another cluster when at least one element in it is connected to at least two elements in another cluster" (Saaty, 2005).

6.3.2 Pairwise comparisons

After constructing the ANP network, the next phase is the measurement and data collection stage which involves compiling a list of experts to provide judgements for pairwise comparisons. Both the AHP/ANP derive ratio scale priorities by making paired comparison of elements on common elements. The subjective judgements are to be entered and assigned a numerical value based on the nine-point scale suggested by Saaty (1990) to obtain the corresponding pairwise judgement matrices. A score of 1 indicates the equality between the two elements whereas score 9 represents the dominance of the row element in the matrix over the column element. A reciprocal value is automatically assigned in the opposite position in the matrix, i.e. $a_{ji} = 1/a_{ij}$.

In this model, pairwise comparisons are identified according to the connections developed in Table 6.11 and then relevant pairwise comparison matrices are created accordingly. The columns in the table present the parent elements, while the rows present the children elements in the structure. For example, G1 is a parent element and A1 through to F2 are its children elements. The elements that are to be pairwise compared are always all in the same cluster. They are compared with respect to their parent element, i.e. the element from which they are connected. There are a number of comparison matrices for every parent element, and one comparison matrix for elements in the same cluster originating from the same parent element. For example, there are four comparison matrices for criterion B6, one for each of clusters A, B, C and G. Elements within D cluster cannot be compared with respect to B6 because there should be at least two entries of 1 available within any cluster to perform pairwise comparisons. Therefore, A1, A2, and A5 through to A9 are pairwise compared with respect to B6; B1 through to B5, B7 and B8 are pairwise compared with respect to B6; C1 and C5 are pairwise compared with respect to B6; and G1 through to G4 are pairwise compared with respect to B6.

This results in local priorities of the children elements with respect to the parent element. It is only necessary to make $n(n-1)/2$ comparisons to establish the full set of pairwise judgements, where n denotes the number of elements. For example, six pairwise comparison questions are required for A1 because n = 4 for the alternatives outer dependence on A1, while for A8, twelve pairwise comparison questions are needed because n = 4 for the inner dependence within the technical cluster, and also n = 4 for the alternatives outer dependence on A8. An example of such pairwise question is: “In selecting an appropriate backbone infrastructure technology in rural areas of developing countries, which influences Fibre optic cable technology more, ease of installation or ease of maintenance? Conversely, given the ease of installation, which of these technologies are more dominant, Fibre optic cable or Satellite?”

The comparisons among all other elements were done in the same way and produced a total of 92 judgement matrices which include 674 pairwise comparison questions for both inner and outer dependencies developed within the network. Appendix F presents relevant tables showing how these numbers of judgement matrices and pairwise questions were determined. Additionally, since the clusters in this network are not equally important, their weights in the cluster matrix are obtained by pairwise comparisons. Each cluster is taken in turn as a parent cluster, and the other clusters connected to it are pairwise compared for importance with respect to their influence on it (Saaty, 2005). For example, one of the cluster comparison questions addressed to the experts is: “Which features influence the selection of rural telecommunications backbone infrastructure more, Economic or Technical?”

The obtained cluster weights are used in constructing the supermatrices to weigh up all the elements in the unweighted supermatrix. It should be noted that the pairwise comparisons to assess the influence of a cluster on all other clusters is actually what distinguishes the ANP from the AHP.

6.3.2.1 Pairwise comparisons questionnaires

Obviously, the task of addressing a large number of pairwise questions required in this study would be enormous requiring intensive efforts and extended time. Hence, in order to economise efforts and establish a more rational approach to collect judgements from qualified telecommunication experts, it was decided to design two types of questionnaires that contain the same material but differ in layout, which were web-based and text-type questionnaires. Appendix G presents both questionnaire types that were used to collect answers to pairwise questions. A particular focus is given to the web-based approach as it brought greater value to group decision making by allowing users to give critical input from anywhere in the world.

1. Web-based questionnaires: In today's world, the internet has become an integral part of our daily life; it offers a valuable opportunity for collecting experts' opinions. Hence, the author created the required online questionnaires by using a subscription-based service to an online survey provider which allowed for many extra benefits including more responses are being received from around the world. To minimise experts' time and efforts, the questionnaires were divided into several independent links, so that any respondent can choose and answer the questions that are relevant to his/her expertise. The survey links were then e-mailed to a group of telecoms experts as well as academics who were identified from online forums as described in subsection 5.2.2 and published in three online forums. They were sent to staff-members attached to several telecoms companies such as, British Telecoms (BT), Siemens, Alcatel, NEC, etc. They were also circulated within several schools of Electrical and Electronic Engineering in Libya and the UK.

The results were collected, stored automatically by the service provider and appeared in the account instantly. Thus, one can view the completed surveys individually or download them as a spreadsheet. In addition, the individual results were e-mailed to the author as soon as they were collected which proved to be practical in this study. This approach was found to be an efficient data collecting technique as it constituted a group decision support system that permitted experts from all over the world to express their preferences through the internet. It allowed for greater and more effective participation in the decision making process by bringing about greater consensus. It also eliminated the need for face-to-face meetings, which usually dominated by one person to promote his/her own views.

2. Text-type questionnaire: It was designed using Microsoft Word and sent to reachable persons who prefer the portability and convenience that the paper format allows in providing judgements in this form. They are mainly academics with a busy-schedule from Electrical and Electronic Engineering schools at nearby universities within the city of Manchester. Several completed questionnaires were collected using this method.

Several case studies in the literature applied AHP/ANP indicated the use of three to seven respondents (Saaty, 1994). Hence, in order to minimise experts' biases when answering pairwise comparison questions, four judgements were obtained for each particular question as shown in Appendix H. All judgements obtained from individual experts using either of the two methods described above were tabulated and then aggregated into a representative group judgement by calculating the geometric mean for each pairwise question (see, section 4.5) as shown in Appendix H. The aggregated group judgements were then arranged in corresponding consensus pairwise judgement matrices and finally entered into *SuperDecisions* to perform necessary computations to synthesise the results. Figure 6.4 illustrates how the judgements are entered into the *SuperDecisions*. It shows an example of pairwise comparisons between alternatives, with respect to 'Reliability'.

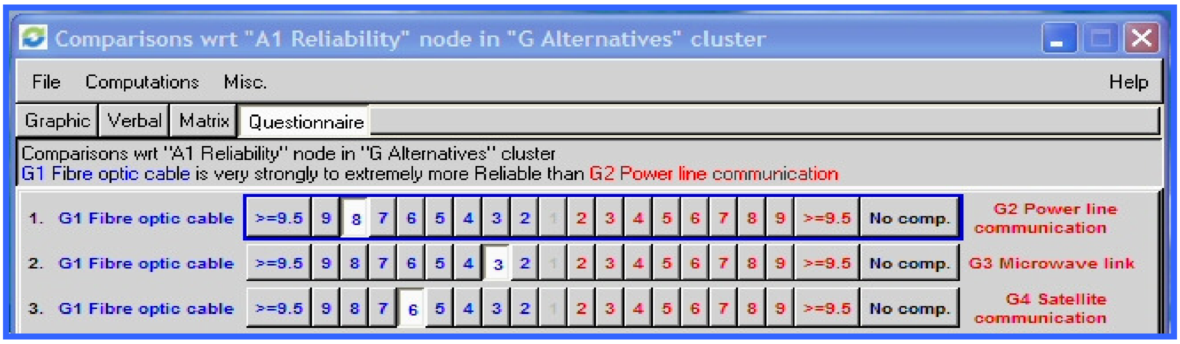


Figure 6.4 An example of *SuperDecisions* pairwise comparison process

While a score of 1 indicates equality between the two technologies, the blue scores represent the dominance of the row element in the matrix (e.g., G1) over the column element (e.g., G2) and the red scores are vice versa. The question being asked is "With respect to reliability, which technology is more reliable: Fibre optic technology or power line communication?" The group judgement was that G1 'is between '*very strongly'* and '*extremely*' more reliable than G2. Thus, a 'blue' score of 8 corresponding to the group judgement regarding this question is clicked to highlight the technology providing more reliability relative to the technology providing less reliability. A reciprocal value is automatically assigned in the opposite position in the matrix.

6.3.2.2 Determining the normalised weights

The next stage of the process includes the computations of the relative importance of the elements. For each comparison matrix a local priority vector is computed, by applying the eigenvector approach described in chapter 4, subsection 4.3.2.3.1. Appendix I presents all pairwise comparisons matrices including their eigenvectors and consistency ratios in the last column. An example of such aggregated comparison matrix is shown in Table 6.13. It compares the alternatives with respect to the reliability factor. Its corresponding eigenvector is also shown in the rightmost column.

Table 6.13 Comparison matrix of alternatives with respect to reliability

Alternatives	G1	G2	G3	G4	**Eigenvector**
G1	1.000	8.240	3.350	5.730	**0.580**
G2	0.121	1.000	0.178	0.217	**0.044**
G3	0.299	5.630	1.000	3.830	**0.262**
G4	0.175	4.610	0.261	1.000	**0.114**
					CR=0.0958

From the above table one can see that in terms of reliability, the Fibre optic cable technology has the highest priority (0.580) followed by Microwave links and Satellite with (0.262) and (0.144), respectively. The less reliable technology is the Power line communication (0.044). Since the value of *CR* is less than 0.1, this matrix is considered of acceptable consistency. *SuperDecisions* can deal with the issue of improving matrices' consistency, by identifying the most inconsistent judgements. The matrix consistency can then be improved by providing more consistent judgements by the decision makers so that $CR \leq 0.1$. For further explanation of consistency and how to calculate it, one can refer to chapter 4, subsection 4.3.2.3.1.

6.3.3 Formation of supermatrices

The eigenvector derived in this way is then entered as a part of some column of a supermatrix. It represents the impact of a given set of elements in a component on another element in the system, where a component in a supermatrix is the block, defined by a cluster name at the left and a cluster name at the top. If an element has no influence on another element, its influence priority is assigned zero. The formation of a supermatrix in the ANP allows for the resolution of the effects of the interdependence that exists between the elements of the system (Saaty, 2006).

In order to facilitate all matrix algebra the *SuperDecisions* computations module was used to perform all needed computations involving the supermatrix. The three supermatrices, associated with this model are created as shown in Appendix J. Table J.1 illustrates the unweighted supermatrix that contains the local priorities derived from pairwise comparisons throughout the network; they can be read directly from this matrix. The weighted supermatrix shown in Table J.2 is obtained by multiplying all the elements in a component of the unweighted supermatrix by the corresponding cluster weight, i.e. each block of column eigenvectors belonging to a component is weighted by the priority of influence of that component. This makes the entire columns sum to unity exactly, i.e. the weighted supermatrix is said to be 'column stochastic'. Finally, the limit supermatrix is obtained by raising the weighted supermatrix to the powers until all columns are identical to within a certain decimal place (i.e. to allow for convergence of the interdependent relationships) (Saaty, 2010). This shows that the network is strongly connected and its supermatrix is irreducible (i.e. there is a path between any two of its elements).

The final values of priorities of all the elements are obtained by normalising each block, so that the columns of the limit supermatrix become identical. The values of the priorities of all elements can be read from any column as can be seen in Table J.3.

6.3.4 Final results

Figure 6.5 presents the final global scores of alternatives obtained by using the *SuperDecisions* 'Synthesis' command. The results are displayed in three different ways: The Raw column shows the limiting priorities obtained from the limiting supermatrix; the most usual form used to report priorities is the Normals column, in which the results are normalized by the cluster weight, and finally the Ideals column shows results obtained by dividing the values in either of the two columns by the largest value in that column.

Graphic Scale	Alternatives	Ideals	Normals	Raw	Ranking
	G1 Fibre optic cable	0.3174	0.1438	0.0322	**3**
	G2 Power line communication	0.2555	0.1158	0.0259	**4**
	G3 Microwave link	1.0000	0.4532	0.1013	**1**
	G4 Satellite communication	0.6337	0.2872	0.0642	**2**

Figure 6.5 Final results as obtained from *SuperDecisions* synthesis command

The obtained results indicate that the Microwave link technology is the most preferred alternative with a normalised priority of 45.32%, Satellite communication is the second one, with a score of 28.72%, followed by the Fibre optic cable and the Power line communication with 14.38% and 11.58%, respectively. According to the 'Ideals' priorities; Microwave has a priority of 1.0, i.e. 100%, so the scores of Satellite, Fibre optic and Power line are 63.37%, 31.74% and 25.55%, respectively. *SuperDecisions* has also been used to produce the priorities shown in Table 6.14. It contains the relative importance of all criteria considered in the model. For example, under the limiting (raw) priorities' column, one can observe that the most important factors among all are the Return on investment criterion with a priority of 17.15% followed by the Funding criterion with 15.94%.

Table 6.14 The relative importance of the criteria

Cluster	Criteria	Priorities (%)	
		Normalised	Limiting
(A) Technical	(A1) Reliability	18.73	2.42
	(A2) Ease of maintenance	21.70	2.81
	(A3) Remote network management	17.05	2.21
	(A4) Compatibility	2.62	0.33
	(A5) Ease of installation	2.80	0.36
	(A6) Scalability	11.98	1.55
	(A7) Bandwidth	13.42	1.74
	(A8) Flexibility	3.50	0.45
	(A9) Latency	8.21	1.06
(B) Infrastructure	(B1) Coverage range	58.32	7.96
	(B2) Security of physical infrastructure	5.04	0.69
	(B3) Proposed usage	12.07	1.65
	(B4) Availability of skilled technicians	3.24	0.44
	(B5) Access to existing ~ infrastructure	4.74	0.65
	(B6) Remoteness of area	3.22	0.44
	(B7) Rollout time	5.84	0.80
	(B8) Parallel infrastructure	7.53	1.03
(C) Economic	(C1) Operating cost	16.39	7.53
	(C2) Funding sources	34.70	15.94
	(C3) Capital cost	7.84	3.60
	(C4) Return on investment	37.32	17.15
	(C5) Economic development of area	3.75	1.72
(D) Social	(D1) Demand	64.96	1.74
	(D2) Affordability	20.49	0.55
	(D3) Population density	9.91	0.27
	(D4) Community of interest	4.65	0.12
(E) Regulatory	(E1) Spectrum availability	56.99	0.67
	(E2) Licensing constraints	27.45	0.32
	(E3) Rights of way	15.56	0.18
(F) Environmental	(F1) Terrain topography	56.81	0.71
	(F2) Climatic conditions	43.19	0.54

According to the Normalised priorities column, the most important criterion is 'Demand' with a priority of 64.96%, followed by 'Coverage' with 58.32%. Among the technical criteria 'Ease of maintenance', 'Reliability' and 'Remote network management' criteria have the highest priorities of 21.71%, 18.73% and 17.05%, respectively. The 'Spectrum' and ‘Terrain topography’ factors are regarded as the most important within the regulatory and environmental clusters, with priorities of 56.99% and 56.81%, respectively. The relative importance of all criteria considered in the model can be read from table 6.14.

6.4 Conclusion

This chapter reports on the application of the analytic hierarchy/network processes to enhance the selection process of an essential rural infrastructure technology. Initially, a general AHP model for rural telecommunication infrastructure selection was created using a phase-by-phase approach, from structuring the selection problem, measurement and data collection, determining the normalised weights, to synthesis – finding solution to the problem. A four level hierarchy is structured to represent the problem at hand. This hierarchy adopts a basic AHP approach that includes pairwise comparisons of all elements.

Pairwise comparisons are made with respect to elements of one level of hierarchy given the element of the next higher level of hierarchy, from the level of criteria down to the level of alternatives. To build up such a general model, telecommunication experts from all over the world were invited to make pairwise comparison judgements on the matrices derived from the AHP hierarchy. The collected data were then combined using the geometric mean and the normalised priority weights were determined for the combined matrices using Excel. Finally, at the synthesis phase, the model was established by combining the normalised priority weights in each level of the hierarchy.

The final results showed that Satellite technology is the most preferred alternative as it achieved the highest score in this AHP model with a normalised priority of 29.21%. Microwave came next with a priority of 28.59% and then Fibre and Power line technologies with 22.07% and 20.08% respectively. In addition, regarding criteria comparison with respect to the goal, it was found that the technical criterion had the highest priority of 29.31%, expressing a certain advantage among others, which indicates more importance of the technical aspects in comparison to other economic, infrastructure, etc. factors. The lowest priorities were for social, environmental and regulatory aspects with 6.90%, 5.84% and 5.63%, respectively. The most important subcriterion among all was the ‘operating cost’ with a priority of 11.47% followed by ‘coverage’ with 9.20% and ‘funding’ with 6.37%. The top ten factors comprised a variety of subcriteria that belong to all criteria except the regulatory criterion. The least important subcriteria among others considered in the model with priorities of less then 1% were ‘climatic conditions’, ‘latency’, ‘proposed usage’, ‘spectrum’ and ‘demand’ with 0.93, 0.70, 0.62, 0.40 and 0.28 respectively.

The AHP was capable of structuring the problem and providing a systematic approach to decision making allowing for diverse qualitative factors to be examined in a mathematical model, which can help to reduce the time needed to evaluate the alternatives. However, the priority scores of the four technologies were actually quite close to each other and although satellite technology achieved the highest score, it was only above Microwave's score by less than 1% and fibre optic's score was just less than 2% higher than that of power lines. Hence, it becomes questionable for the decision makers to arrive at a consensus decision to select any of the alternatives. This outcome implies that the simplicity of the hierarchical structure and linear unidirectional hierarchical relationship among criteria and subcriteria in the AHP method hid important issues, such as interdependence among qualitative factors and interaction among decision making levels and so oversimplified the problem.

The ANP method can overcome the shortcomings of the strict hierarchical structure inherent in AHP. Subsequently, a generic ANP model for rural telecoms infrastructure selection developed in this chapter considered all kinds of dependencies systematically. This task was fulfilled through a new survey questionnaire, which included the dependency half-matrix that was distributed to experts. The response rate reached 70%. The majority rule was used to aggregate the responses into a single matrix in accordance to a predefined scale. A majority condition of 57% experts' consensus was considered as a minimum requirement for any entry that indicates the existence of a direct relationship between any pair of elements.

In this chapter, it was shown numerically and graphically that the problem has inner dependencies, outer dependencies and feedback links developed among the elements in the network structure, which excludes the hierarchy form and calls for the network form to model such a rural technology selection problem. Once all possible dependencies among elements were identified, it was found that 92 judgement matrices, which include 674 pairwise comparison questions, were required in this network. *SuperDecisions* was used to construct the model accordingly and the experts were consulted again to assess the strength of these dependencies through pairwise comparison questions questionnaires. A particular focus was given to the web-based surveys because they brought greater value to group decision making by allowing users to give critical input from anywhere in the world. Since the clusters in this network are not equally important, their influences on each other were also pairwise compared and their weights were tabulated in the cluster matrix.

The computations of the relative importance of the elements by estimating the relative importance between any two elements in each matrix and calculating the relevant eigenvectors were done by *SuperDecisions.* The software was also used to deal with the issue of improving matrices' consistency, by measuring the inconsistency of each matrix and identifying the most inconsistent judgements and eventually constructing the supermatrix using the eigenvectors of the individual matrices. The final values of priorities of all the elements were obtained by normalising each block, so that the columns of the limit supermatrix became identical.

The obtained results indicate that Microwave technology is the most preferred alternative with a normalised priority of 45.32%, Satellite communication is the second one, with a score of 28.72%, followed by the Fibre optic and the Power lines with 14.38% and 11.58%, respectively. The relative importance of all criteria considered in the model was also obtained. For example, the most important criterion among all is the 'demand' with a priority of 64.96% followed by the 'coverage' with 58.32%. Among the technical criteria 'ease of maintenance', 'reliability' and 'remote network management' criteria have the highest priorities of 21.71%, 18.73% and 17.05%, respectively. The 'spectrum' and 'terrain topography' factors are regarded as the most important within the regulatory and environmental clusters, with priorities of 56.99% and 56.81%, respectively.

The ANP model developed in this chapter provides value to telecoms planners by raising their awareness to the availability of such a method and to researchers by demonstrating a new and novel application of ANP, which is meant to be a generic model applicable across different rural areas. It is recognised that the decision making process involved in any particular implementation would be different depending on the rural environment involved. In fact, this is one of the strengths of the ANP representing its ability to adapt a basic framework to a particular situation. Each application area can have defined for it a set of criteria deemed important for that area. A decision criterion that a telecoms company considers to be crucial can easily be added to this generic model.

One of the limitations of the ANP is the dependency on the decision makers because the weightings obtained are based on the expert's subjective opinion. Hence, the obtained results reflect the preferences of experts who made the judgements and therefore, should not be viewed as an objective assessment of the relative suitability of the four technologies as backbone infrastructure in rural areas. However, they should be thought of as an input to the decision-making process rather than its end. This process could be refined with experience, optimising the accuracy and time taken to reach proper decisions in this regard.

7. FORMULATION AND ESTIMATION OF THE ANP BOCR MODEL

7.1 Introduction

This chapter aims at choosing the most suitable telecommunication infrastructure technology for rural areas using the BOCR-based ANP approach described in Chapter 4 to create the evaluation and selection framework. It commences by developing the model from the perspective of decision makers and stakeholders. Four technology alternatives are evaluated with respect to approximately 38 technological, infrastructure, economic, social, regulatory and environmental factors. As explained in section 7.2, several factors were used in more than one merit.

The main goal and the alternatives follow the same process described in the previous AHP/ANP analysis presented in chapters 6. The objective is to select the alternative, which is the most beneficial and offers the most opportunities while at the same time incurs the least cost and poses the lowest risk.

The strategic criteria are determined and described and the model was structured by creating three networks: the top-level network, which contains the BOCR merits and the strategic criteria that are used to evaluate the importance of the BOCR. The control criteria networks that are placed under the BOCR networks; and the decision networks, which include alternatives cluster and are created for each high priority control criterion/subcriterion.

The empirical study is conducted and presented. The means described in chapter 5 are used to collect numerical input for the decision model. The interactions among clusters as well as within clusters in the decision subnet are identified and discussed. The process of the computation and synthesis of the results is described and illustrated by examples. The alternatives' synthesis at the top-level network is explained, which also include linking their weights with the BOCR priorities. The chapter concludes by performing sensitivity analysis as illustrated by the sensitivity graphs.

This wide-ranging approach for selecting rural telecommunication infrastructure technology proposed in this chapter helps telecoms decision makers decide on the most appropriate backbone alternative for rural areas and offers the potential to reach proper decisions in this regard.

7.2 Development of the ANP model

Frequently, the alternatives from which a choice must be made in a decision-making situation have both benefits and costs associated with them. However, benefits, opportunities, costs, and risks cannot be combined; simply because they are opposing forces (Saaty and Vargas, 2006). Thus, in this model, it is useful to construct separate benefits, opportunities, costs and risks networks, with the same decision alternatives located in each. To achieve that, *SuperDecisions* was utilised to create the decision model where the criteria are further analysed and grouped into BOCR subnetworks (subnets) according to the framework introduced by Saaty (2001). A visual representation of the proposed decision-making framework is given in Figure 7.1.

Based on the factor groupings, the model was constructed as a multi-layer network. The top portion of the model consists of four separate multi-level networks: one each for the Benefits, Opportunities, Costs and Risks (BOCR) subnets and an overall goal element. These subnets constitute the essential part of the proposed decision framework. The structure within each of these subnets consists of clusters of factors (i.e. the clustering of factors is performed in which the control criteria/subcriteria are further grouped into clusters) that are relevant to the sub-goal of the subnet. As explained below, the factors were then classified among the subnets based on their definitions within the context of rural areas of developing countries given in Appendix A.

The bottom part of Figure 7.1 illustrates a typical decision subnet, which is also an important part of the ANP decision framework that consists of three clusters: alternatives, decision makers, and other stakeholders (actors). A detailed explanation of the structure of each subnet and the decision subnet is given in the following subsections.. Generally, an explicit positive outcome that is occurring in the near future is assigned to Benefits, whereas a definite short-term negative attribute is placed under Costs. Long-term, uncertain factors are allocated to either Opportunities or Risks, depending on whether they contribute positively or negatively to the goal (Saaty, 2008). For example, “economic development of area” criterion was assigned to economic opportunities, because it is an uncertain positive economic outcome that may or may not occur in the future.

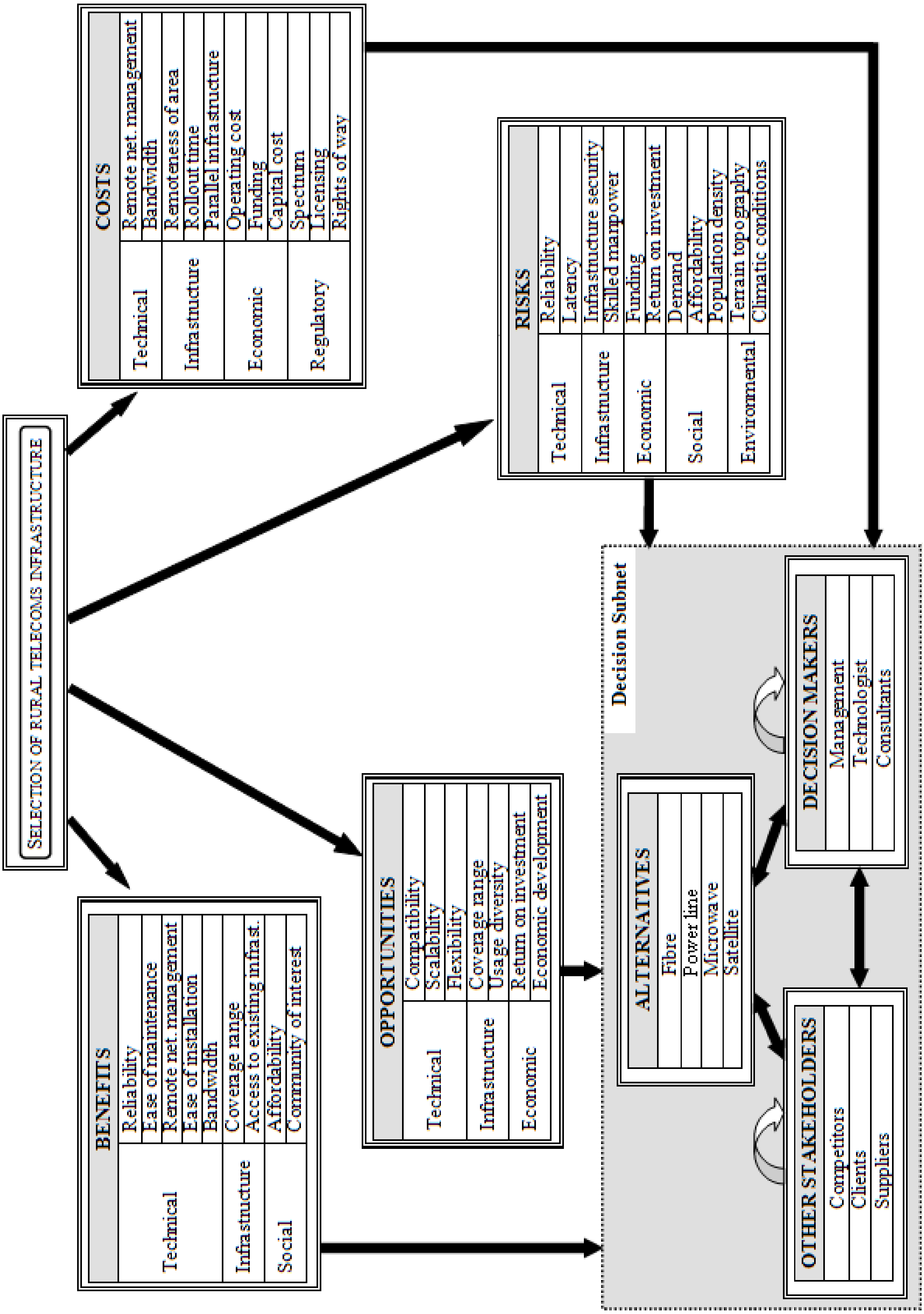


Figure 7.1 The ANP-based rural telecoms infrastructure selection framework

It is important to note that usually for such decision problems; each merit would have a different structure than the other merits (Saaty, 2010). Hence, whenever applicable, the same factor was used in more than one BOCR network, such as a benefit criterion which may result in increased cost. For example, the benefit of equipping the potential technology with remote network management system will increase the cost of the technology to be selected. To reflect this, this criterion was also assigned to the Costs subnet. Also, the Reliability factor was placed under the benefits merit, so that when the alternatives were compared in terms of Reliability, the pairwise question being asked was "which alternative is more reliable". Conversely, the Reliability was also placed under the risk merit, and the question asked was "which alternative is less reliable", i.e. creates more problems in the future, in terms of frequent outage, etc. Similar interpretations were made to other factors such as bandwidth, coverage, affordability, and return on investments. The criteria coding (i.e. A1, A2… F2) used for Benefits, Opportunities, Costs and Risks subnets are unchanged as previously defined in section 5.4.

7.2.1 Setting strategic criteria and deriving BOCR weights

This stage allows one to look at the problem from more general perspective. That is, from the viewpoint of the strategic criteria and subcriteria described below. These strategic criteria also enable the connection of the Benefits and Opportunities results with those for Costs and Risks and presentation of the final result. The strategic criteria and subcriteria in this model were identified from the vast reading of the literature examined, e.g., ITU (1998, 1997, 2000 & 2006), Saaty (2005a, 2005b, 2006 & 2008), Sherif (2006), etc. Several people familiar with the subject area were also consulted. It was quickly realised that there is no single expert in all the criteria considered. Four primary strategic criteria believed to adequately consider telecoms decision makers concerns about the selection and deployment of rural telecoms infrastructure were put forward by most of the experts. These are: Public welfare, Infrastructure enhancement, Quality of service, Telecoms company (Telco) benefits. Each of these criteria has two subcriteria under them considered relevant to this problem. Although some of these factors are self-explanatory, a brief explanation of all of them is given below.

1. **Public welfare**: in considering the overall public wellbeing, the concerns include:
    i. Rural communities' wellbeing: refers to the quality of life of rural residents. A rural telecommunications network that serve the interest of the community, could lead to improved level in the standard of living of that

community. For instance, by ensuring contact with relatives, friends and the outside world; and

ii. Stimulating rural telecommunications infrastructure development: Telecoms infrastructure in rural areas is an essential infrastructural component. Hence, promoting its development represents one of the critical concerns in most developing countries

2. **Infrastructure enhancement**: highlights the importance of developing the infrastructure in rural areas. To achieve that, two aspects need to be addressed:

   i. Extending rural connectivity: can untimely benefit all people, particularly in providing modern telecoms services in remote rural areas; and

   ii. Promoting universality of access to rural telecommunications services: Achieving the "universal access" to telecommunication services in rural and remote areas of developing countries is an ultimate aim. It is highly reflected in the current thinking, papers, presentations and recommendations of the ITU development sector.

3. **Quality of service**: the quality of telecoms infrastructures and services is determined, *inter alia*, by the level of client satisfaction and network reliability.

   i. Client satisfaction: is evaluated in terms of the time to obtain a satisfactory answer to a request or a complaint; and

   ii. Network performance: refers, *inter alia*, to the geographic availability and reliability of the rural telecoms network to provide the optimum services over the maximum distance at the minimum installed cost.

4. **Telco benefits**: telecommunications companies which are normally also the infrastructure providers aims to secure these two factors:

   i. Revenues**:** refers to recovering the investment and generate profits from deploying the planned telecoms infrastructure; and

   ii. Market**:** refers to establishing market presence and increasing market penetration in rural settings which are characterised by market failure.

These strategic criteria/subcriteria are prioritised by conducting the usual pairwise comparisons of the AHP against each other and then calculating the eigenvectors. Benefits, opportunities, costs and risks are not equally important in such a highly socio-technical decision. Their weights are to be derived with respect to the strategic criteria/subcriteria explained above using an AHP ratings model. The analysis is similar to the AHP but BOCR groups are used instead of the alternatives at the bottom level of the hierarchy as shown in Figure 7.2. The strategic criteria/subcriteria are used to rate the importance of the top rated alternative for each of the Benefits and that for Opportunities as to how they help with respect to each criterion. Also, rating the top rated alternative for the Costs and Risks as to how much they hinder with respect to each criterion (Saaty, 2010). Thus, the derived priorities of BOCR (b, o, c, and r) will be used later when applying the additive-negative formula to synthesise the results (detailed in section 7.3.4).

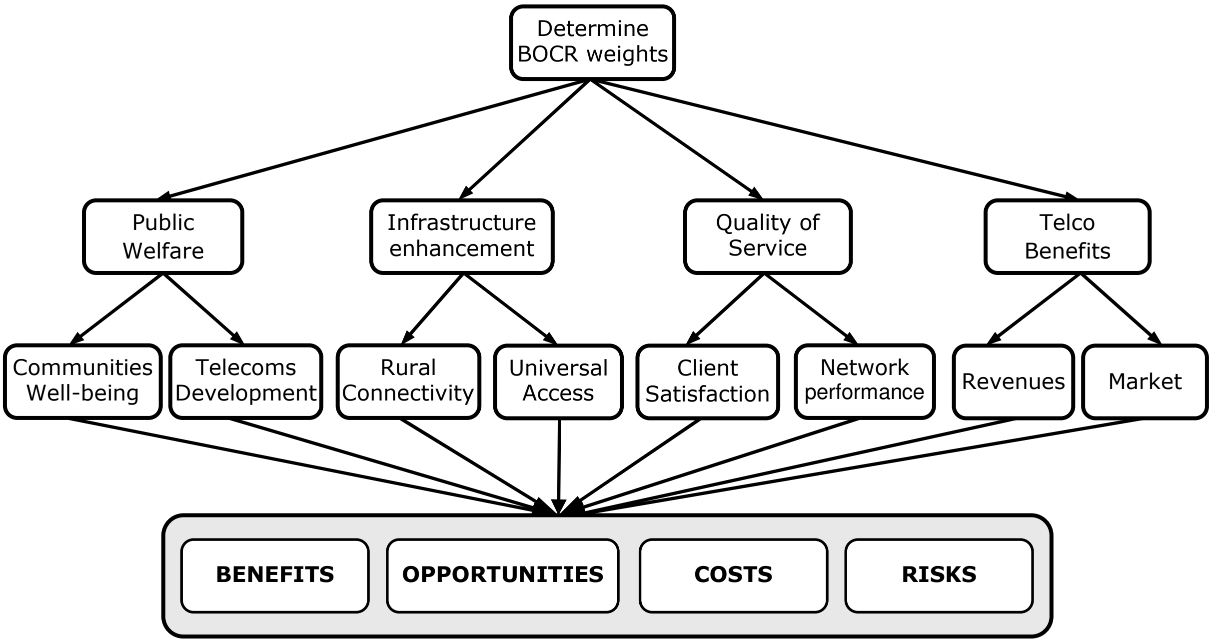


Figure 7.2 AHP ratings model for BOCR prioritisation

7.2.2 The BOCR subnets

On the upper part of Figure 7.1, one can see the four BOCR subnets. The control criteria, whose priorities were established through pairwise comparison, were then attached to these subnets. They themselves also contained subnets attached to the bottom level decision subnets that include the decision alternatives and two clusters of relevant actors (stakeholders). As shown in Figure 7.1, the total number of criteria and subcriteria used in the networks is 38 of which there are six control criteria selected in making such a decision, namely: technical, infrastructure, economic, social, regulatory and environmental. They are treated as independent of each other and thus their hierarchies are built to represent that. The Risks subnet includes five control criteria clusters: technical, infrastructure, economic, social, and environmental. The Costs subnet includes four control criteria while all other subnets include three. There are two control criteria which were considered in all subnetworks. These are related to the technical and infrastructure aspects. The economic criterion was included in all models except the benefits. The social criterion is included in the Benefits and Risks network.

7.2.2.1 The Benefits subnet

The Benefits subnet has a sub-goal of maximising benefits which in this model are gains and advantages expected from making a given decision, partitioned into three benefits clusters of control criteria: technical, infrastructure, and social. The numerical priorities derived from the Benefits subnet represent the intensity of positive contribution imparted by each alternative to the overall decision goal. Thus, for a specific alternative, its priority is the greater the better. The structure of the Benefits subnet and its underlying clusters and respective elements is shown in Figure 7.3. A brief description of each criterion customised according to B, O, C, or R categories interpretations is provided below (an extensive discussion of the criteria is presented in Appendix A). Note that *italics* in the following paragraphs correspond to the concerned criteria.

The 'technical' control criterion cluster includes five subcriteria that are found to affect the selection process. They represent the functionality and technical features thought to offer the most benefits to the proposed rural telecoms system. Uncertain rural environments require infrastructure technologies with high *Reliability* that encompasses consistent speed and services, together with *Ease of maintenance* and user friendliness of the equipment.

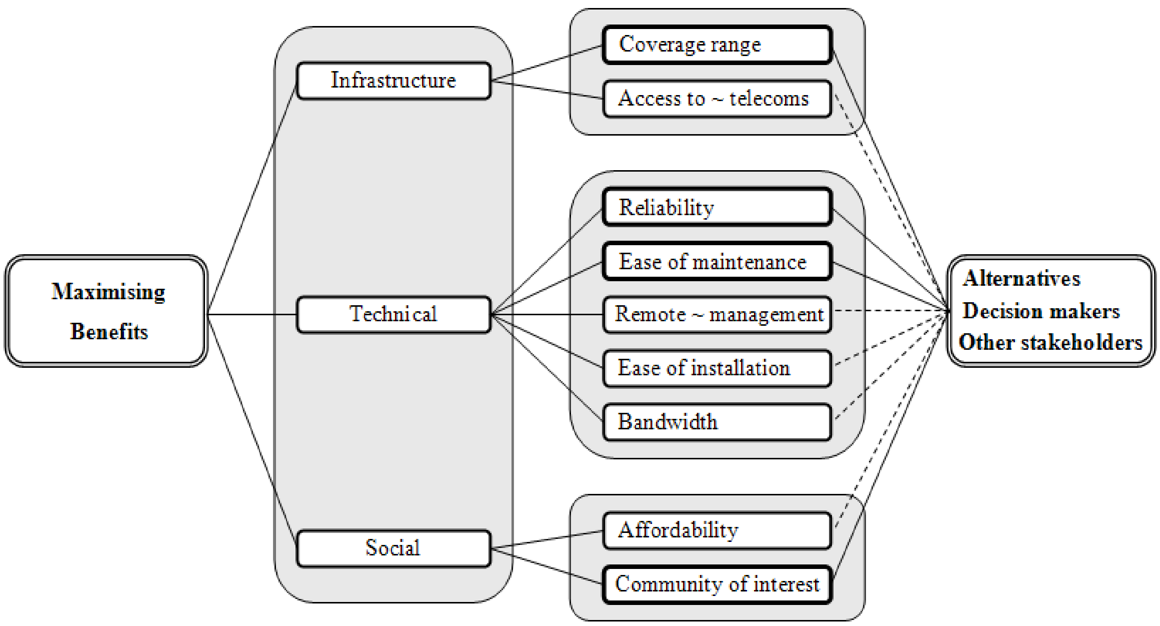


Figure 7.3 The Benefits subnet structure

Since rural equipment cannot sustain rapid turnover, it is chosen under the constraint that repairing services and spare parts cannot be provided for long periods of time. Hence, *Remote network management* capabilities, comprising centralised maintenance facilities, capable of reconfiguring circuits to maintain services enable maintenance staff to remotely carry out system checks and remotely locate faults at card level so that repairs can be made by semi-skilled personnel is a potential benefit. Besides, considering the relative degree of difficulty for the construction of backbone telecommunications infrastructure at localities characterised by being remote and rural, significant challenges are expected and therefore, *Ease of installation*, depending on transmission medium chosen and applicability to rural area where it will be built and housed, must be one factor that offers substantial benefits to the chosen technology, since evidently each technology has a finite upper limit to what data rate it can provide. Technically, high data transfer capacity of the infrastructure technology, including both upstream and downstream *Bandwidths* at which one can upload and download information is of great benefit, and implies a well-designed telecoms system, which helps enhance new potential services.

The infrastructure benefits encompass *Coverage* characterising how well the population targeted by the planned telecoms service is able to use and benefit from it. Also, in order to facilitate and minimize the investments required to build the backbone infrastructures to cover a remote and dispersed rural environment, one has to consider *Access to existing telecoms infrastructure,* which calls for sharing of telecommunications network infrastructures by making use of the existing public infrastructure assets such as radio towers, electricity clamps, public buildings, etc.

The social benefits include: *Affordability* of the rural inhabitants to gain access to reasonably priced telecoms services by providing public access at a nominal cost. The *Community of interest* is the technology's ability to accommodate the needs of a collaborative group of users that share common cultural, linguistic or economic ties.

7.2.2.2 The Opportunities subnet

The Opportunities subnet is a three-layered network with a sub-goal of securing the best opportunity. It should be seen in a different light than benefits and the alternative that scores the highest in this subnet will contribute the largest positive score to the opportunities subnet. From a telecoms planners' perspective, opportunities originate from three clusters representing: technical, infrastructure, and economic related aspects. They are identified for this portion of the model as shown in Figure 7.4 and discussed below.

The 'technical' cluster comprises three criteria believed to present most opportunity to influence the selection process. Complying with technology standards and use of the open standards option implies fulfilment of *Compatibility* requirements between adjacent and overlapping networks, i.e. the ability of the planned rural telecommunications infrastructure technology to co-exist or operate with other already deployed dissimilar technologies. Also, the other two factors enhance opportunities since *Scalability*, refers to the ability to expand the technology's capacity incrementally without substantial hardware or software configurations and *Flexibility* refers to the technology's ease of expansion within rural areas.

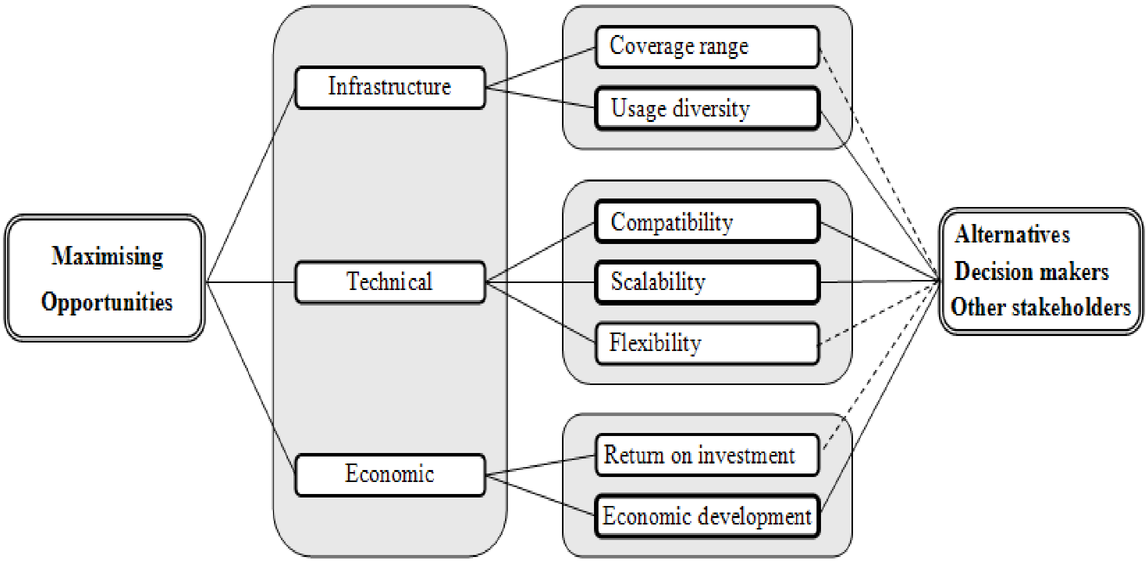


Figure 7.4 The Opportunities subnet structure

The 'infrastructure' related issues cluster includes two factors that contribute to the promotion of opportunities within rural environments, namely: *Coverage* that refers to the technology's coverage range expected in rural settings. It is expressed by an operator in the form of percentages of population in a given area able to access the service or percentage of the geographic area in a given country where the service is available, and *Usage* refers to the expected future usage of the proposed new services.

The economic opportunities cluster comprised two factors. These are, respectively: the *Return on investments* criterion which refers to the expected return on capital investments representing a decision's positive effects, considering that rural telecommunications infrastructures technologies and services are expected to pay for themselves, unlike roads and water and *Economic development of area,* which is the ability of the planned rural infrastructure to promote rural areas economic activities.

7.2.2.3 The Costs subnet

The sub-goal of the Costs subnet is to minimise the total costs. Hence, the alternatives' priorities derived from this subnet represent the level of negative impact each alternative has on the overall decision objective, and so for a specific alternative's priority, it is the smaller the better, i.e. a smaller priority value in this subnet corresponds to less cost of an alternative. Thus, the Benefits clusters present the positive side of the proposed technology, while the Costs clusters exhibit those factors that are detrimental to it. In fact, this is how the model balances out the pros and cons and ultimately yields a decision that incorporates all possible factors. Hence, in this model, the costs of choosing one alternative over the others arise from the technical, infrastructure, economic and regulatory costs clusters as can be seen in Figure 7.5 and explained below.

The 'technical' costs cluster includes *Remote network management,* representing the costs of equipping the chosen alternative with remote monitoring and management capabilities and since each technology has a finite upper limit to what data rate it can provide. Hence, increasing this *Bandwidth* limit incurs additional expenditures. The 'infrastructure' costs cluster encompasses *Remoteness of area* as the isolation of rural districts from urban centres implies that the distance to the public switched network impacts the costs of the infrastructure. This also applies to the *Rollout time* needed to deploy the proposed technology, which is directly proportionate to the costs. The lack of *Parallel infrastructure* that refers to the readily available power sources, accessible roads and transport hinders both mobility and accessibility in such areas and will subsequently increase the cost of establishing, operating and maintaining telecoms networks.

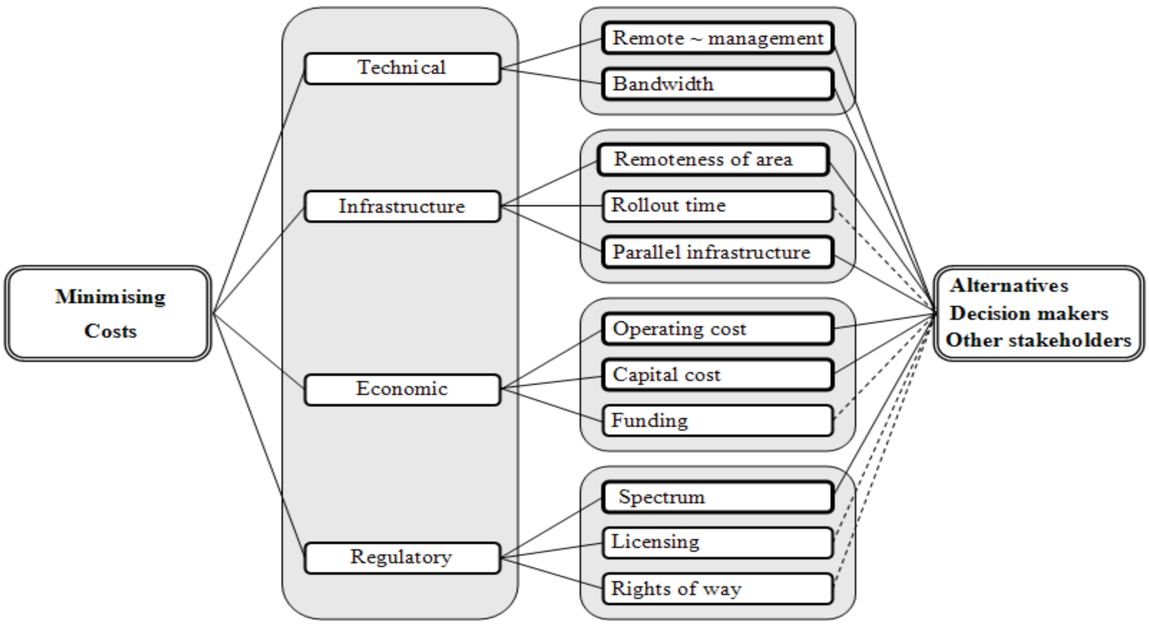


Figure 7.5 The Costs subnet structure

The elements under the 'economic' costs cluster are rather self-explanatory. These are: *Operating costs* necessary for the day-to-day expenditures that include costs of maintenance, training, testing, spares, etc.; *Funding* required to enter rural areas that usually suffer from market failure; and the technology's *Capital cost*s to cover activities such as purchases, deployment, recovery costs, etc.

The policy environment determines the extent and type of coverage together with the speed of rollout of the rural infrastructure. It directly influences the choice of infrastructure and its associated expenditures. Hence, the 'regulatory' cluster contains potential cost factors that include: *Spectrum* which is in many countries auctioned off to the highest bidder and so a high price has to be paid for some frequencies; *Licensing* constraints that hinder the potential use of newer cost-effective technologies and results in potentially more costly solutions; and *Rights of way* where substantial expenditures are required to provide spaces along national road/train networks for installation of rural telecoms networks.

7.2.2.4 The Risks subnet

Unlike the Benefits, Opportunities, and Costs models, the Risks model is slightly different, as risks are defined as the negative uncertainties in the decisions taken regarding the choice of rural telecoms infrastructure. The objective is to minimise the risks by choosing the alternative with the smallest risk. In this model, risks come from several different fronts, such as economic, social technical, environmental, and infrastructure. These risks would play a pivotal role in arriving at the final decision. The clusters and their elements representing these aspects are shown in Figure 7.6 and summarised below.

The 'technical' risk cluster is represented by two criteria: *Reliability* of the telecoms systems, which can be affected in times of inclement weather or disasters posing unforeseen service interruptions to the rural telecoms infrastructure networks; and *Latency*, which particularly impacts voice services because they are more susceptible to severe degradation with high latency. Thus, low latency is best. For example, one drawback of satellite-based technologies is a higher latency time and a significant delay due to the long distance travelled by data.

The 'infrastructure' risk cluster includes two factors: *Security of physical infrastructure* that refers to the vulnerability of the equipment and cables installed in rural surroundings to theft and vandalism; and *Availability of skilled personnel* that tend to be rarely found in rural areas and the requisite skills may not even exist in the immediate locality, causing an increased risk in the installation, operation and maintenance of rural systems.

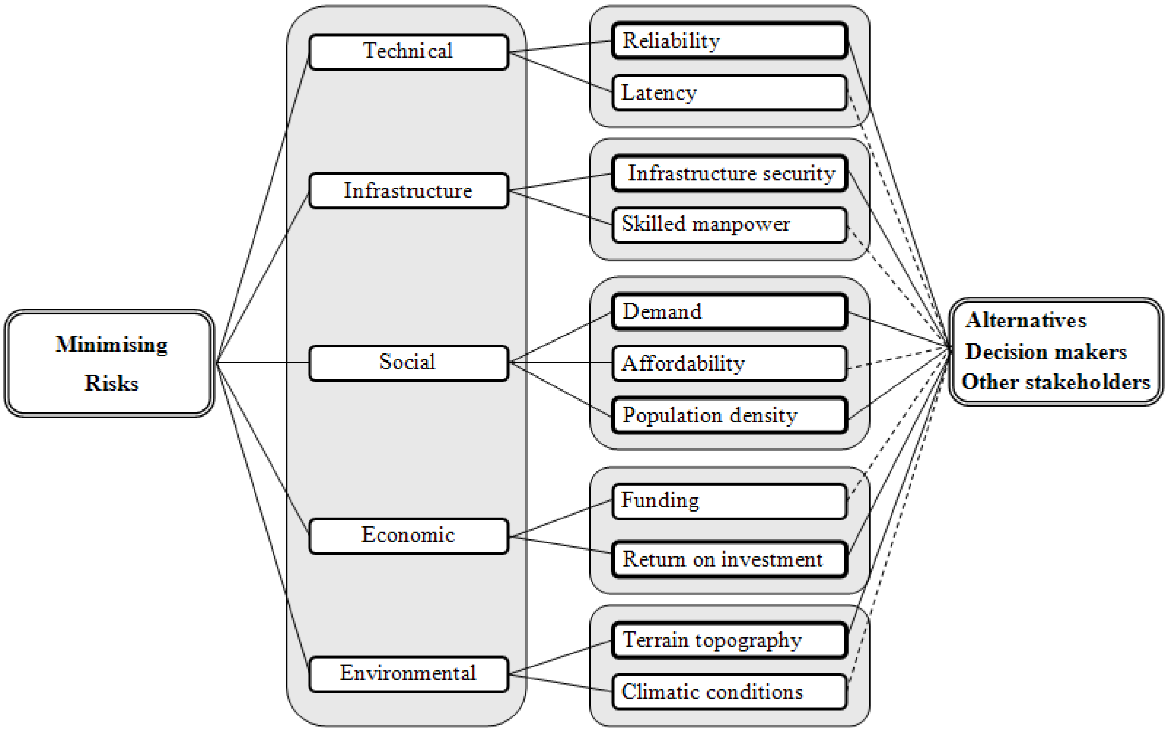


Figure 7.6 The Risks subnetwork structure

The *Funding* and *Return on investment* factors are placed under the 'economic' risk cluster because getting access to the necessary funds to enter the rural areas that are suffering from market failure constitutes a real challenge. Also, the suppliers of the financial resources required for the deployment of rural telecommunication infrastructures and services are interested in a profitable return on capital investments. However, decisions on investment in rural areas are based on the returns which that investment will make and this usually takes time to mature. Hence, if the investment is unprofitable in the long run, it is unwise to invest in it now and so this factor is directly related to the degree of risk and policy frameworks.

The 'social' risk cluster contains criteria such as: *Demand* because in general, the demand for telecommunications in the rural areas of developing countries is low and hence, the deployment of rural telecommunication infrastructures becomes risky if the demand for communication services is not sufficient to make the proposed services economically viable; *Affordability* since the delivery of affordable and accessible services to populations with very low disposable incomes and general lack of capital to acquire telecommunication equipment is a real challenge; and *Population density* because rural areas are mostly characterised by having relatively low population density and dispersed settlement pattern, which results in lack of market incentives for investment in infrastructures.

Finally, the environmental risk cluster encompasses two factors: *Terrain topography* encountered in rural areas like difficult geographical terrain, e.g. lakes, rivers, hills, grasslands, mountains or deserts, constitute a primary challenge and render the construction of wire telecommunication networks very risky; and harsh *Climatic conditions* that characterise rural settings. Factors such as lightning, fluctuations in temperature and wind speed, heavy rainfall or snow will directly affect the deployment of telecommunication systems.

7.2.3 The Decision subnet

After identifying the important attributes for consideration in selecting a rural telecoms infrastructure, the evaluation continues by using one criterion at a time. As mentioned in chapter two, there are several various stakeholders and multiple criteria involved in a rural telecommunications system. The issue is how does one select the right rural telecommunications technology so that all stakeholders benefit, especially when the challenges that face the planners are complex and multi-dimensional? Also, planners do not usually consider the indirect benefits, which are essential for development, of providing telecommunications to rural areas. It is therefore decided to consider multiple perspectives of the relevant stakeholders involved in the selection process by developing an influence network, i.e. an ANP decision subnet, for each criterion, which typically consists of a cluster of alternatives and several clusters of actors (stakeholders). Consequently, besides the 'Alternatives' cluster, which contains four technology options that were previously assigned in chapter 5, two other clusters, namely: 'Decision makers' and 'Other stakeholders' were included in this subnet to incorporate various stakeholders in the decision making process, as shown in the lower portion of Figure 7.1 and detailed in Figure 7.7. Each actor in the influence network has specific needs or desires and contributes to the success or failure of the chosen alternative.

The inclusion of stakeholders in this model was accomplished after intensively reviewing the literature, e.g., Banville et al. (1998); Saaty (2001); (Saaty and Ozdemir, 2005); Saaty and Vargas, 2006); (Saaty and Cillo, 2008); (Saaty, 2010), etc. as well as consulting several telecoms experts who took part in certain stages of this research. A brief overview of stakeholders' classifications within the context of this thesis will be given below. However, for more detailed explanations about the incorporation of stakeholders into MCDM approach, one can refer to Banville et al. (1998).

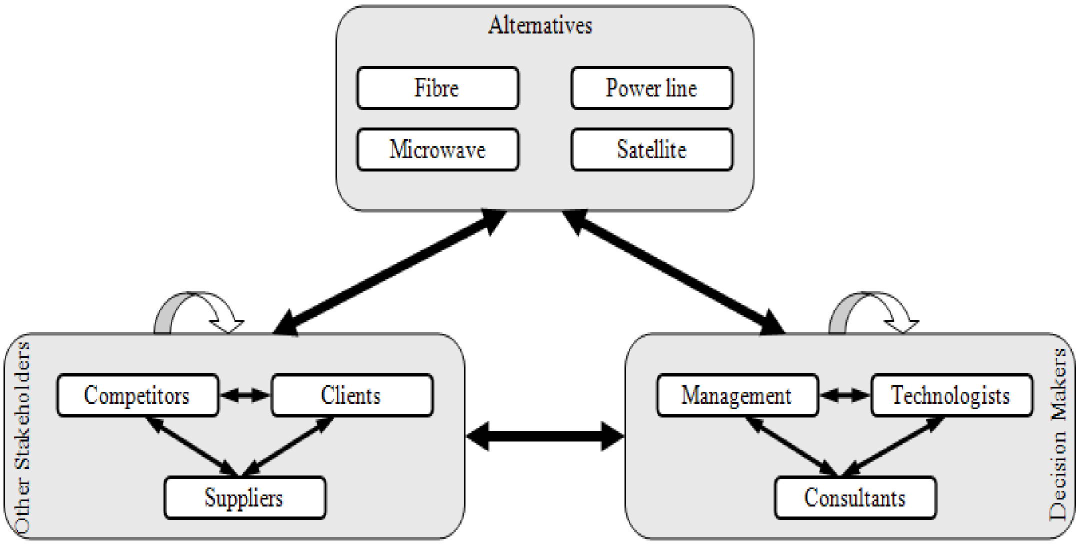


Figure 7.7 The Decision subnetwork structure

The term 'Stakeholders' generally refer to those persons who have a vested interest in some common problem situation. It is vital to consider stakeholders in decision making, and also in activities such as planning telecommunications infrastructure. In fact, the final decisions pertaining to the kind of infrastructure that must be deployed will be made by the telecommunications infrastructure providers and operators. It is proposed that a concise but deep treatment on the identification and choice of pertinent stakeholders must be included in the ANP model. This will be a significant step towards realising the aims of the model. Besides, the concept of stakeholders has a holistic implication and further enhances the holistic approach articulated in this thesis.

Governments of some developing countries have made Universal Access a key priority and have accordingly placed certain access imperatives with respect to rural areas, on their network providers and operators. Hence, the initiative for planning telecoms backbone networks will occur as a result and therefore, relevant agents from telecoms providers will start the iterative process of identifying and classifying the stakeholders. These agents can categorise the possible stakeholders that would take part in the planning process or at least in the selection process, according to the following constituencies (Banville et al., 1998).

It should be noted that the categories are non-mutually exclusive, but this will assist in moving towards an exhaustive a list of stakeholders as possible.

1. **Standard Stakeholders**
   - All those that both affect the problem and are affected by the selection problem and play a crucial role in the choice of the infrastructure to be deployed.
2. **Fiduciary Stakeholders**
   - All those persons that can and may act on behalf of clients, who are deemed important and necessary for the selection process but may not be personally affected by the infrastructure.
3. **Silent Stakeholders**
   - All those persons that could be affected by the selection and deployment of the infrastructure but do not exist or are unable to voice their concerns, during the selection exercise.

Based on the above, for the sake of this study, three types of decision makers that can participate in the decision making process including: 'Management', 'Technologists', and 'Consultants' were identified. They were coded H1, H2 and H3, respectively, and placed under the 'Decision Makers' cluster. H1 and H2 can be regarded as 'standard stakeholders' in terms of Banville et al. (1998) while H3 can be characterised as 'fiduciary stakeholders' as 'consultants' may participate in the process of formulating the problem and affect the way it is solved but they are not personally affected by the solution. Besides, considering other actors (people or groups) who could be affected by the decision outcome; the 'Other Stakeholders' cluster contained three groups: 'Competitors', 'Clients', and 'Suppliers'. who were also coded I1, I2 and I3, respectively. I2 can be classified as 'silent stakeholders' since 'clients' have no direct control over the resources or uncertainties deemed relevant for solving the problem.

7.3 Empirical study and computational results

7.3.1 Model input

After constructing the model, the means described in chapter 5 were used to collect numerical input for this decision model. Two different types of surveys were needed. The first survey involves the usual approach of eliciting responses from experts for subjective judgements to determine the weights of the criteria and subcriteria in the ANP model. For this purpose the online questionnaires introduced in chapter 6 were reutilised for collecting the data. It should be noted that some of the data needed in this model were taken from the AHP/ANP models developed in Chapter 6. However, there was a need to modify some pairwise questions to comply with the new structure developed in this chapter. All the questions used in the online surveys can be seen in appendix G.

In the second survey regarding the collection of input data for pairwise comparison within each decision subnet, other online questionnaires were developed and distributed to several experts. The aim was to capture all the interactions and influences within each decision subnet, at the same time limiting the number of questions presented to participants. Appendix K shows a sample of such questionnaires. It includes one of the 21 sets of questions utilised for pairwise comparisons of all the alternatives with respect to a specific criterion, which is in this case, *Ease of maintenance*. Table 7.2 shows all the interactions identified within the decision subnets such as, the alternatives impact on the actors within the 'Decision Makers' cluster, the inner dependency of actors within this cluster and 'Other stakeholders' cluster, etc.

Once the pairwise comparisons were completed, three responses were obtained for each question. Implementing ANP in a group entails aggregating the preference of individuals into a consensus rating to aggregate individual judgements into a representative group judgement, i.e. to reveal the aggregated group judgements. Hence, the geometric mean was computed using Excel to derive the group average responses for each pairwise question. For example, if three respondents regard the benefits priority of "Fibre" over "Microwave" as 2, 5, and 7, respectively, then the aggregate preference of "Fibre" technology alternative would be $[(2)(5)(7)]^{1/3} = 4.12$, i.e. the individual judgements are replaced by the geometric mean for the group. The basis for using this method has been justified mathematically by Aczel and Saaty (1983) and Saaty (2001).

The obtained group judgements were then used to perform necessary matrix algebra calculations. The global priorities of the criteria/subcriteria shown in the last column of Table 7.1 are obtained by weighting their priorities by those of their parent criterion and also by priority of their merit. For example, the normalised global priority for *Reliability* is computed by multiplying its local priority (0.2881) times the priority of its corresponding control criterion *Technical* (0.4491) times the weight of its corresponding merit "Benefits" which is obtained from the rating system, thus equalling 0.3097 x 0.4491 x 0.2881 = 0.0401, *normalised* = 0.1294. From the 'normalised' global priorities column of each subnet, one can observe that in the case of Benefits, *Coverage* obtained the highest global priority (0.2755). In the case of Opportunities, *Usage* is the most important factor with priority of 0.2344. Among Costs, a relatively high priority was assigned to regulatory costs subcriterion *Spectrum* (0.1232) while the environmental risks factor *Terrain topography* was assigned the highest risk priority of 0.1277.

By examining the priorities of the subcriteria depicted in Table 7.1, one can determine which ones should have a decision subnet attached.

Table 7.1 Criteria/ subcriteria and their priorities

BOCR	**Criteria**	**Subcriteria**	**Priorities**	
			Local	**Global**
Benefits	Technical **0.4491**	Reliability	0.2881	**0.1294**
		Ease of maintenance	0.2738	**0.1230**
		Remote network management	0.1518	0.0682
		Ease of installation	0.1294	0.0581
		Bandwidth	0.1569	0.0705
	Infrastructure **0.3287**	Coverage range	0.8382	**0.2755**
		Access to existing infrastructure	0.1618	0.0532
	Social **0.2222**	Affordability	0.1943	0.0432
		Community of interest	0.8057	**0.1790**
Opportunities	Technical **0.3535**	Compatibility	0.3987	**0.1409**
		Scalability	0.3861	**0.1365**
		Flexibility	0.2152	0.0761
	Infrastructure **0.3125**	Coverage	0.2500	0.0781
		Usage diversity	0.7500	**0.2344**
	Economic **0.3340**	Return on investment	0.3105	0.1037
		Economic development	0.6895	**0.2303**
Costs	Technical **0.2410**	Remote network management	0.5005	**0.1206**
		Bandwidth	0.4995	**0.1204**
	Infrastructure **0.2644**	Remoteness of area	0.4568	**0.1208**
		Rollout time	0.0890	0.0235
		Parallel infrastructure	0.4542	**0.1201**
	Economic **0.2882**	Operating cost	0.4260	**0.1228**
		Funding	0.4223	**0.1217**
		Capital cost	0.1517	0.0437
	Regulatory **0.2064**	Spectrum	0.5968	**0.1232**
		Licensing	0.2027	0.0418
		Rights of way	0.2005	0.0414
Risks	Technical **0.1915**	Reliability	0.6612	**0.1266**
		Latency	0.3388	0.0649
	Infrastructure **0.1544**	Infrastructure security	0.7995	**0.1234**
		Skilled manpower	0.2005	0.0310
	Economic **0.2161**	Funding	0.3310	0.0715
		Return on investment	0.6690	**0.1446**
	Social **0.2878**	Demand	0.4315	**0.1242**
		Affordability	0.1429	0.0412
		Population density	0.4255	**0.1225**
	Environmental **0.1502**	Terrain topography	0.8500	**0.1277**
		Climatic conditions	0.1500	0.0225

Saaty (2005) recommends considering the subcriteria of global priorities that cover about 70% to 80% of the total priorities. For example, the normalised priorities of the Benefits subnet's subcriteria illustrated in the upper part of Table 7.1 sum to 1.0. By picking only the subcriteria that received higher priorities yields: *Reliability*, *Ease of maintenance*, *Coverage* and *Community of interest*. Their priorities account for approximately: 0.1294 + 0.1230 + 0.2755 + 0.1791 = 0.7070 (≈ 71%) of the total Benefits subcriteria weights. Hence, according to Saaty (2005), to economise efforts, these four subcriteria are considered sufficient to represent all the benefits and thus to have decision subnets created under them. In Figure 7.3, they were distinguished from the less significant subcriteria by using bolded borders and were connected to the decision subnet using 'straight lines'. The other subcriteria in the Benefits subnet have relatively low priorities and are excluded from having decision subnets attached.

Using the same approach described above, four subcriteria having 74% of the total Opportunities priorities were selected from the Opportunities subnet to create decision subnets under them. These are: *Compatibility*, *Scalability*, *Usage diversity* and *Economic development of area*. In the Costs subnet, seven subcriteria representing 85% of the Costs priorities were chosen to build decision subnets under them. These are: *Remote network management*, *Bandwidth*, *Remoteness of area*, *Operating cost*, *Funding* and *Spectrum*. While for the Risks subnet, six subcriteria accounting for 77% of the total Costs priorities were considered to attach decision subnets under them: *Reliability*, *Infrastructure security*, *Return on investment*, *Demand*, *Population density* and *Terrain topography*. Consequently, 21 subcriteria have been used as control subcriteria, each with its decision network, to perform the analysis as shown in Table 7.1 (highlighted in boldface in the global priorities column).

It should be noted that by keeping all the subcriteria in the model (mainly for comparative purposes), one can get a simplified model. Saaty (2001) had proposed and actually implemented this approach in his ANP decision model "National Missile Defence (NMD) system". Shang et al. (2004) had also proved the invariance of the alternatives rankings based on this approach. Moreover, since the 21 subcriteria received their higher priorities as a result of the prioritisation of BOCR, hence, with different priorities of BOCR, one may have a different set of distinguished subcriteria. However, according to Saaty (2005), with few exceptions, most of these high-priorities subcriteria are sufficiently dominant that perturbing the priorities of BOCR is unlikely to replace them with other factors.

7.3.2 Interactions and pairwise comparisons of the decision subnet

After completing the model structure, interactions among clusters as well as within clusters in the decision subnet were identified according to the connections developed by applying the same means introduced in Chapter 6 (subsection 6.3.1). All possible interactions within this subnet are illustrated in Table 7.2. For example, each of the three types of decision makers included in the decision makers cluster would have different views and can express their preference over alternatives. Thus, this cluster interacts with the alternative cluster. On the other hand, each alternative also included backward interactions with this cluster, i.e. can impact all decision makers as indicated in Figure 7.7 by the double sided arrow between the two clusters. The same interactions apply among the alternatives and the other stakeholders clusters indicating that the alternatives influence other stakeholders and vice versa.

The three two-way arrows shown in Figure 7.7 represent the outer dependencies and feedbacks among cluster members, where as the loop indicates inner dependencies within the cluster. For example, under 'Other stakeholders' cluster, the suppliers have influence on competitors as well as on clients. In addition, management can impacts both the technologists and consultants. The alternatives are not dependent on each other and so no loop can be seen in their cluster.

Table 7.2 The decision subnet dependency matrix

	Fibre	Power line	Microwave	Satellite	Management	Technologists	Consultants	Competitors	Clients	Suppliers
G1 Fibre	0	0	0	0	1	1	1	1	1	1
G2 Power line	0	0	0	0	1	1	1	1	1	1
G3 Microwave	0	0	0	0	1	1	1	1	1	1
G4 Satellite	0	0	0	0	1	1	1	1	1	1
H1 Management	1	1	1	1	0	1	1	0	0	1
H2 Technologists	1	1	1	1	1	0	1	0	0	1
H3 Consultants	1	1	1	1	1	1	0	0	0	1
I1 Competitors	1	1	1	1	1	0	1	0	1	1
I2 Clients	1	1	1	1	1	1	0	1	0	1
I3 Suppliers	1	1	1	1	1	1	1	1	1	0

Pairwise comparisons of the alternatives were made using the online questionnaires to survey different groups represented in the decision subnets as displayed in Figure 7.7. The respondents represent both the decision makers and other stakeholder groups. For instance, a telecoms company executive would identify himself as "Management" in the "Decision Makers" group. In addition to the different degree of preference each group have regarding the alternatives, the other stakeholders are also impacted by the alternatives to various degrees. These are built into the model by answering questions such as: when considering *Ease of maintenance*, with respect to "Satellite", how much more is Technologist affected than Management? Moreover, the decision makers group will have influence and interaction with the other stakeholders and vice versa. All interactions, influences, and preference are captured in the decision subnet and pairwise compared by using the online questionnaires.

7.3.3 Computation and synthesis

The priority vectors derived from the pairwise comparisons within a decision subnet are summarised in a supermatrix. It captures all influences, interactions and preferences of the actors on the alternatives and on each other and also considers the impacts of alternatives on actors. A decision subnet level supermatrix contains all local priority vectors. To illustrate this, Table 7.3 shows the unweighted supermatrix of the decision subnet under one of the Benefits subcriteria, namely *Reliability*. The submatrices on the main diagonal represent inner dependencies of actors within each cluster, while those off the main diagonal represent outer dependencies of actors among clusters.

Table 7.3 Unweighted supermatrix for the reliability subcriterion

		G				**H**			**I**		
		G1	G2	G3	G4	H1	H2	H3	I1	I2	I3
G	G1	0.0000	0.0000	0.0000	0.0000	0.0787	0.5092	0.4723	0.2956	0.4853	0.2155
	G2	0.0000	0.0000	0.0000	0.0000	0.2329	0.0573	0.0557	0.1995	0.0833	0.1239
	G3	0.0000	0.0000	0.0000	0.0000	0.2475	0.3115	0.3033	0.2484	0.2750	0.2000
	G4	0.0000	0.0000	0.0000	0.0000	0.4408	0.1220	0.1687	0.2566	0.1564	0.4606
H	H1	0.6586	0.1094	0.7306	0.0852	0.0000	0.8476	0.8639	0.0000	0.0000	0.7049
	H2	0.1562	0.3090	0.0810	0.6442	0.1905	0.0000	0.1361	0.0000	0.0000	0.0841
	H3	0.1852	0.5815	0.1884	0.2706	0.8095	0.1524	0.0000	0.0000	0.0000	0.2109
I	I1	0.1865	0.5584	0.6870	0.6586	0.3325	0.0000	0.8000	0.0000	0.1250	0.1429
	I2	0.1265	0.1220	0.1265	0.1562	0.5278	0.1901	0.0000	0.8750	0.0000	0.8571
	I3	0.6870	0.3196	0.1865	0.1852	0.1397	0.8099	0.2000	0.1250	0.8750	0.0000

The table above shows that under the three columns from the 'Decision Makers' H1, H2 and H3, there are three submatrices. The first one consists of four rows representing each alternative's degree of impact on each decision maker: H1 'Management', H2 'Technologists' and H3 'Consultants'. The rows 5-7 of the second submatrix are on the main diagonal showing the influence of decision makers on each other. For example, Management's influence on Consultants is 0.8639 and Technologists influence on Consultants is 0.1361. This can be interpreted as Management has 6 times more influence on Consultants than Technologists do. Finally, Rows 8-10 represent the impact of the Other stakeholders cluster on the Decision Makers cluster. For instance, I2 'Clients' influence on H1 'Management' is 0.5278 while the influence of I3 'Suppliers' on H1 'Management' is 0.1396. In other words, Clients have 4 times more influence on Management than Suppliers.

Next, there is a need to also prioritise the clusters under the decision subnets corresponding to each of the control subcriteria. It is essential to know the importance of the clusters to which the elements belong because the final priorities depend on that. The experts were therefore asked to compare the decision subnet clusters in order to establish the cluster matrix weights. For example, for the decision subnet under the *Reliability*, each cluster was taken in turn as the parent cluster and pairwise compared with all the clusters it connects to for importance with respect to their influence on it. An example of the formulated cluster's paired comparison question being asked to prioritise the above influences is: Given the alternatives cluster, which cluster influences it more, Decision Makers or Other Stakeholders, and how much more? Once all clusters are compared, the priorities of clusters within the decision subnet under the *Reliability* are obtained as shown in Table 7.4.

Table 7.4 Clusters priorities under *Reliability*

Reliability	Alternatives	Decision Makers	Other Stakeholders
Alternatives	0.0000	0.1047	0.0852
Decision Makers	0.8333	0.6370	0.6442
Other Stakeholders	0.1667	0.2583	0.2706

By multiplying a cluster entry of Table 7.4 into the corresponding entries of Table 7.3, one can get the weighted supermatrix illustrated in Table 7.5.

Table 7.5 Weighted supermatrix for the *Reliability*

		G				H			I		
		G1	G2	G3	G4	H1	H2	H3	I1	I2	I3
G	G1	0.0000	0.0000	0.0000	0.0000	0.0082	0.0533	0.0495	0.0708	0.1162	0.0184
	G2	0.0000	0.0000	0.0000	0.0000	0.0244	0.0060	0.0058	0.0478	0.0200	0.0106
	G3	0.0000	0.0000	0.0000	0.0000	0.0259	0.0326	0.0318	0.0595	0.0659	0.0171
	G4	0.0000	0.0000	0.0000	0.0000	0.0462	0.0128	0.0177	0.0615	0.0375	0.0393
H	H1	0.5489	0.0912	0.6089	0.0710	0.0000	0.5399	0.5503	0.0000	0.0000	0.4541
	H2	0.1302	0.2575	0.0675	0.5369	0.1213	0.0000	0.0867	0.0000	0.0000	0.0542
	H3	0.1543	0.4846	0.1570	0.2255	0.5157	0.0971	0.0000	0.0000	0.0000	0.1359
I	I1	0.0311	0.0931	0.1145	0.1098	0.0859	0.0000	0.2066	0.0000	0.0951	0.0387
	I2	0.0211	0.0203	0.0211	0.0260	0.1363	0.0491	0.0000	0.6654	0.0000	0.2319
	I3	0.1145	0.0533	0.0311	0.0309	0.0361	0.2092	0.0517	0.0951	0.6654	0.0000

By raising the above column stochastic matrix to large powers until it converges, one gets the limit matrix depicted in Table 7.6 containing the eigenvectors of the original matrix. The *SuperDecisions* software's power method is stopped when the difference between components of the priority vector obtained at the k^{th} power and at the $(k+1)^{th}$ power is less than some predetermined small value (Saaty, 2001). The limit supermatrix of the *Reliability* benefits shown in Table 7.6 has the same form as the weighted supermatrix, except all columns are the same and each column sums to one.

The priorities (raw values) of the four alternatives can be read from any column of this supermatrix: G1 = 0.0398, G2 = 0.0161, G3 = 0.0315 and G4 = 0.0319 respectively, which can be normalised to 0.3337, 0.1349, 0.2639 and 0.2675 correspondingly. To compute the idealised priority for each technology alternative under a specific subcriterion, one can use this formula: *Ideals = limit value / highest limit value*. Hence, for the Reliability subnet, the idealised values of the alternatives are: G1 = 0.0398/0.0398 = 1, G2 = 0.0161/0.0398 = 0.4043, G3 = 0.0315/0.0398 = 0.7910 and G4 = 0.0319/0.0398 = 0.8016.

Table 7.6 Limit supermatrix for the *Reliability*

		G				H			I		
		G1	G2	G3	G4	H1	H2	H3	I1	I2	I3
G	G1	0.0398	0.0398	0.0398	0.0398	0.0398	0.0398	0.0398	0.0398	0.0398	0.0398
	G2	0.0161	0.0161	0.0161	0.0161	0.0161	0.0161	0.0161	0.0161	0.0161	0.0161
	G3	0.0315	0.0315	0.0315	0.0315	0.0315	0.0315	0.0315	0.0315	0.0315	0.0315
	G4	0.0319	0.0319	0.0319	0.0319	0.0319	0.0319	0.0319	0.0319	0.0319	0.0319
H	H1	0.2543	0.2543	0.2543	0.2543	0.2543	0.2543	0.2543	0.2543	0.2543	0.2543
	H2	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829
	H3	0.1842	0.1842	0.1842	0.1842	0.1842	0.1842	0.1842	0.1842	0.1842	0.1842
I	I1	0.0877	0.0877	0.0877	0.0877	0.0877	0.0877	0.0877	0.0877	0.0877	0.0877
	I2	0.1321	0.1321	0.1321	0.1321	0.1321	0.1321	0.1321	0.1321	0.1321	0.1321
	I3	0.1397	0.1397	0.1397	0.1397	0.1397	0.1397	0.1397	0.1397	0.1397	0.1397

Similarly, the alternatives priorities for all other subcriteria under the Benefits subnet were derived using the same approach. The overall syntheses under this subnet are displayed in Table 7.7 as normalised and idealised values. These results indicate that Fibre is the most favoured option as far as the *Reliability* is concerned. In a similar vein, Microwave is the most beneficial in case of *Ease of maintenance*, while Satellite and Power line are dominating in terms of *Coverage* and *Community of interest* respectively.

Table 7.7 Prioritisation of alternatives for criteria/ subcriteria under benefits subnet

Criteria	Technical 0.4491				Infrastructure 0.3287		Social 0.2222	
Subcriteria	*Reliability* 0.2881		*Ease ~ maintenance* 0.2738		*Coverage* 0.8057		*Community ~ interest* 0.8382	
Alternatives	*Normal*	*Ideal*	*Normal*	*Ideal*	*Normal*	*Ideal*	*Normal*	*Ideal*
Fibre	0.3337	1.0000	0.2712	0.7086	0.1074	0.2096	0.2803	0.7089
Power line	0.1349	0.4043	0.0784	0.2048	0.0860	0.1678	0.3954	1.0000
Microwave	0.2639	0.7910	0.3827	1.0000	0.2943	0.5746	0.1740	0.4400
Satellite	0.2675	0.8016	0.2678	0.6999	0.5123	1.0000	0.1503	0.3801

Due to the hierarchical structure of the Benefits subnet, there is neither inner dependence within clusters nor outer dependence among clusters. Thus, the unweighted and weighted supermatrices are identical as can be seen from Table 7.8. The limit supermatrix for the Benefits subnet is shown in Table 7.9.

Table 7.8 Unweighted/ Weighted supermatrix under benefits subnet

	Goal	A	B	D	A1	A2	A3	A5	A7	B1	B5	D2	D4
Maximising Benefits	0	0	0	0	0	0	0	0	0	0	0	0	0
A Technical	0.4491	0	0	0	0	0	0	0	0	0	0	0	0
B Infrastructure	0.3288	0	0	0	0	0	0	0	0	0	0	0	0
D Social	0.2221	0	0	0	0	0	0	0	0	0	0	0	0
A1 Reliability	0	0.2880	0	0	0	0	0	0	0	0	0	0	0
A2 Ease ~ maintenance	0	0.2740	0	0	0	0	0	0	0	0	0	0	0
A3 Remote ~ manage.	0	0.1520	0	0	0	0	0	0	0	0	0	0	0
A5 Ease of installation	0	0.1290	0	0	0	0	0	0	0	0	0	0	0
A7 Bandwidth	0	0.1570	0	0	0	0	0	0	0	0	0	0	0
B1 Coverage range	0	0	0.8380	0	0	0	0	0	0	0	0	0	0
B5 Access ~ infrastruc.	0	0	0.1620	0	0	0	0	0	0	0	0	0	0
D2 Affordability	0	0	0	0.1940	0	0	0	0	0	0	0	0	0
D4 Comm. of interest	0	0	0	0.8060	0	0	0	0	0	0	0	0	0

Table 7.9 Limit supermatrix under benefits subnet

	Goal	A	B	D	A1	A2	A3	A5	A7	B1	B5	D2	D4
Maximising Benefits	0	0	0	0	0	0	0	0	0	0	0	0	0
A Technical	0.2246	0	0	0	0	0	0	0	0	0	0	0	0
B Infrastructure	0.1644	0	0	0	0	0	0	0	0	0	0	0	0
D Social	0.1110	0	0	0	0	0	0	0	0	0	0	0	0
A1 Reliability	0.0647	0.2880	0	0	0	0	0	0	0	0	0	0	0
A2 Ease ~ maintenance	0.0615	0.2740	0	0	0	0	0	0	0	0	0	0	0
A3 Remote ~ manage.	0.0341	0.1520	0	0	0	0	0	0	0	0	0	0	0
A5 Ease of installation	0.0290	0.1290	0	0	0	0	0	0	0	0	0	0	0
A7 Bandwidth	0.0353	0.1570	0	0	0	0	0	0	0	0	0	0	0
B1 Coverage range	0.1378	0	0.8380	0	0	0	0	0	0	0	0	0	0
B5 Access ~ infrastruc.	0.0266	0	0.1620	0	0	0	0	0	0	0	0	0	0
D2 Affordability	0.0215	0	0	0.1940	0	0	0	0	0	0	0	0	0
D4 Comm. of interest	0.0895	0	0	0.8060	0	0	0	0	0	0	0	0	0

To obtain the weighted priority of the alternatives under each Benefit subcriterion, the idealised priorities of alternatives displayed in Table 7.7 are multiplied by the subcriterion weight (or Control Criterion CC). Subcriteria weights are derived from Table 7.9 (Shaded cells), and then normalised after discarding the insignificant subcriteria. For example, the idealised priorities of the alternatives under the *Reliability* subnet are weighted by multiplying them by the *Reliability* normalised weight (0.1830) (i.e. the 3rd row of Table 7.10). The results are shown under column 1 of Table 7.10. This procedure is then repeated for the other subnets under Benefits. The idealised sum of weighted alternatives under the Benefits subnet is obtained by summing columns 1, 2, 3 & 4 as shown in the last column of Table 7.10.

Table 7.10 Idealised alternatives priorities under four subcriteria in the benefits subnet

BENEFITS	Reliability		Ease of maintenance		Coverage range		Community of interest		**Sum of wtd alternatives**	
Ctrl Cri. **CC**	0.0647		0.0615		0.1378		0.0895			
Normalised	0.1830	Col. 1	0.1740	Col. 2	0.3898	Col. 3	0.2532	Col. 4	Col's 1+2+3+4	
Alternatives	Ideals	CC x Ideals	Ideals	CC x Ideals	Ideals	CC x Ideals	Ideals	CC x Ideals	Total	**Ideals**
G1 Fibre	1.0000	0.1830	0.7086	0.1233	0.2096	0.0817	0.7089	0.1795	0.5675	**0.7522**
G2 P. line	0.4043	0.0740	0.2048	0.0356	0.1678	0.0654	1.0000	0.2532	0.4282	**0.5676**
G3 M~wave	0.7910	0.1448	1.0000	0.1740	0.5746	0.2240	0.4400	0.1114	0.6542	**0.8670**
G3 Satellite	0.8016	0.1467	0.6999	0.1218	1.0000	0.3898	0.3801	0.0962	0.7545	**1.0000**

Similarly, the supermatrices and weighted alternative priorities for all other subnets were generated in the same manner and using the same logic shown above. Ultimately, the sum of weighted alternatives for the Opportunities, Costs and Risks subnets were obtained. The final synthesised results are illustrated in Tables 7.11, 7.12 and 7.13. Appendix L illustrates all related supermatrices.

Table 7.11 Synthesised results for the opportunities subnet

OPPOR~TIES	Compatibility		Scalability		Usage		Eco. Develop.		**Sum of wtd alternatives**	
Ctrl Cri~on **CC**	*0.0705*		*0.0682*		*0.1172*		*0.1152*			
Normalised	*0.1900*	*Col. 1*	*0.1838*	*Col. 2*	*0.3158*	*Col. 3*	*0.3104*	*Col. 4*	Cl's 1+2+3+4	
Alternatives	Ideals	CC x Ideals	Ideals	CC x Ideals	Ideals	CC x Ideals	Ideals	CC x Ideals	Total	***Ideals***
G1 Fibre	0.2964	0.0563	1.0000	0.1838	1.0000	0.3158	0.4244	0.1317	0.6876	**0.8638**
G2 Power line	0.9341	0.1775	0.5314	0.0977	0.4009	0.1266	0.3912	0.1214	0.5232	**0.6572**
G3 Microwave	1.0000	0.1900	0.3167	0.0582	0.7519	0.2375	1.0000	0.3104	0.7961	**1.0000**
G3 Satellite	0.3054	0.0580	0.7189	0.1321	0.9188	0.2902	0.4016	0.1247	0.6050	**0.7600**

Table 7.12 Synthesised results for the costs subnet

Costs	Remote ~ Manag.		Bandwidth		Remote. ~ area		Parallel Infra.	
Ctrl Cri~on **CC**	*0.0603*		*0.0602*		*0.0604*		*0.0601*	
Normalised	*0.1419*	*Col. 1*	*0.1417*	*Col. 2*	*0.1422*	*Col. 3*	*0.1414*	*Col. 4*
Alternatives	Ideals	CC x Ideals	Ideals	CC x Ideals	Ideals	CC x Ideals	Ideals	CC x Ideals
G1 Fibre	0.5735	0.0814	0.2248	0.0319	1.0000	0.1422	0.1414	0.0450
G2 Power line	0.2002	0.0284	0.7714	0.1093	0.2246	0.0319	0.3183	0.0913
G3 Microwave	0.2239	0.0318	0.2768	0.0392	0.6036	0.0858	0.6458	0.1414
G3 Satellite	1.0000	0.1419	1.0000	0.1417	0.2047	0.0291	1.0000	0.1213

Table 7.12 (*continued*)

Costs	Operating cost		Funding		Spectrum		**Sum of wtd alternatives**	
Ctrl Cri~on **CC**	*0.0614*		*0.0609*		*0.0616*			
Normalised	*0.1445*	*Col. 5*	*0.1433*	*Col. 6*	*0.1450*	*Col. 7*	Col's 1+2+3+…+7	
Alternatives	Ideals	CC x Ideals	Ideals	CC x Ideals	Ideals	CC x Ideals	Total	***Ideals***
G1 Fibre	0.3809	0.0550	1.0000	0.1433	0.2838	0.0412	0.5399	**0.6563**
G2 Power line	0.9620	0.1390	0.1969	0.0282	0.3701	0.0537	0.4819	**0.5857**
G3 Microwave	0.4724	0.0683	0.4313	0.0618	0.9895	0.1435	0.5718	**0.6950**
G3 Satellite	1.0000	0.1445	0.6926	0.0992	1.0000	0.1450	0.8227	**1.0000**

Table 7.13 Synthesised results for the risks subnet

Risks	Reliability		Infrastr. security		Return ~ investment		Demand	
Ctrl Cri~on **CC**	*0.0633*		*0.0617*		*0.0723*		*0.0621*	
Normalised	*0.1647*	*Col. 1*	*0.1605*	*Col. 2*	*0.1881*	*Col. 3*	*0.1616*	*Col. 4*
Alternatives	Ideals	CC x Ideals	Ideals	CC x Ideals	Ideals	CC x Ideals	Ideals	CC x Ideals
G1 Fibre	0.1785	0.0294	0.6201	0.0995	0.6344	0.1193	0.2676	0.0432
G2 Power line	0.4992	0.0822	0.7633	0.1225	1.0000	0.1881	1.0000	0.1616
G3 Microwave	0.1524	0.0251	0.4121	0.0661	0.1742	0.0328	0.2205	0.0356
G3 Satellite	1.0000	0.1647	1.0000	0.1605	0.2347	0.0441	0.8971	0.1450

Table 7.13 (*continued*)

Risks	Population density		Terrain topography		Sum of wtd alternatives	
Ctrl Cri~on **CC**	*0.0612*		*0.0638*			
Normalised	*0.1592*	*Col. 5*	*0.1660*	*Col. 6*	Col's 1+2+3+4+5+6	
Alternatives	Ideals	CC x Ideals	Ideals	CC x Ideals	Total	***Ideals***
G1 Fibre	0.218	0.0347	0.7821	0.1298	0.4560	**0.5184**
G2 Power line	1.0000	0.1592	1.0000	0.1660	0.8796	**1.0000**
G3 Microwave	0.6535	0.1040	0.6557	0.1088	0.3725	**0.4235**
G3 Satellite	0.3052	0.0486	0.4188	0.0695	0.6324	**0.7190**

According to the results presented in the above tables, one can observe that Satellite scores the highest in the Benefits subnet and, at the same time, it also has the highest Costs and second highest Risks, which will offset its overall ranking. Power line has the lowest scores in all subnets except in Risks, in which it scores the highest. Microwave scores the highest in Opportunities and has the lowest Risks but has the second highest Costs. Fibre scores the second highest in Opportunities and third in Benefits, Costs and Risks. It appears that Fibre and Microwave may be the top choices.

A rating model was then developed in which the BOCR were rated according to five intensities shown in Table 7.14 along with their priorities, which were derived from pairwise comparisons (Saaty, 2005).

Table 7.14 Ratings scale based on personal criteria

	Very high	High	Medium	Low	Very low	**Priority**
Very high	1	2	3	4	5	**0.42**
High	1/2	1	2	3	4	**0.26**
Medium	1/3	1/2	1	2	3	**0.16**
Low	1/4	1/3	1/2	1	2	**0.10**
Very low	1/5	1/4	1/3	1/2	1	**0.06**

From the resulting priorities of the strategic criteria and subcriteria shown underneath them in Table 7.15, one can see that Public welfare has the largest priority (0.3776), followed by Infrastructure enhancement (0.2553), Quality of services (0.2166) and Telco benefits (0.1506). The rating process and the resulting priorities for the BOCR are shown in Table 7.15. The highest ranked alternative from each decision network were rated against the strategic subcriteria. For example, to determine which rating to assign in the Benefits column, one has to know the top alternative under Benefits from Table 7.10, which is "Satellite" and then select the appropriate rating for every cell in the Benefits column from Table 7.15. The question being asked is: "what is the 'merit' of the top alternative under Benefits with respect to each of the strategic subcriteria? Hence, it was observed that Satellite has *high* potential Benefits with respect to rural communities' wellbeing, merely *medium* impact on stimulating rural telecommunications infrastructure development, but *very high* impact in improving rural connectivity, and so on.

The above process was carried out in a similar way for Opportunities, Costs, and finally Risks. Once consensus was reached among experts consulted on the ratings for each of the merits, the resultants weights of the merits were derived as reported at the bottom of Table 7.15. It reveals that Benefits received higher priority (0.3097) over Opportunities (0.2496) while Costs obtained much higher priority (0.2616) over Risks (0.1791). This means that the priorities of the alternatives under Benefits are weighted more heavily. Consequently, Benefits at 31% drive the decision in this model more than the Risks at only 18%.

Table 7.15 Priority ratings for the merits with respect to the strategic criteria

(*V. high = 0.42, high = 0.26, medium = 0.16, low = 0.10, V. low = 0.06*)

Criteria	Subcriteria	Benefits	Opportunities	Costs	Risks
Public welfare 0.3776	Communities wellbeing 0.6845	High	Medium	Medium	Low
	Telecoms development 0.3155	Medium	High	High	Low
Infrastructure enhancement 0.2553	Rural connectivity 0.7619	V. High	Medium	High	Medium
	Universal access 0.2381	Medium	Medium	Medium	Low
Services quality 0.2166	Client satisfaction 0.5745	Medium	High	Low	High
	Network performance 0.4255	Low	Medium	V. High	Medium
Telco benefits 0.1506	Revenues 0.4082	Low	High	Low	Medium
	Market 0.5918	High	Medium	Medium	V. Low
	Priorities *(normalised)*	**b= 0.3097**	**o= 0.2496**	**c= 0.2616**	**r= 0.1791**

An account will be given in the next section on how the final rankings of the four technologies are computed using formulae proposed by Saaty (2001).

7.3.4 The top level synthesis

In order to synthesise the alternatives' priorities at the top level and identify the most suitable alternative, it is essential to link the priorities of the alternatives with the BOCR priorities, i.e. the b, o, c and r are used to weigh the four vectors under BOCR. The synthesised results are shown in Table 7.16.

Table 7.16 Synthesis of the alternatives' overall priorities for BOCR

BOCR	Benefits **b= 0.3097**		Opportunities **o= 0.2496**		Costs **c= 0.2616**		Risks **r= 0.1791**	
Alternatives	Sum from Table 7.10	Sum x b	Sum from Table 7.11	Sum x o	Sum from Table 7.12	Sum x c	Sum from Table 7.13	Sum x r
G1 Fibre	0.7522	0.2330	0.8639	0.2156	0.6563	0.1717	0.5184	0.0928
G2 Power line	0.5676	0.1758	0.6572	0.1640	0.5857	0.1532	1.0000	0.1791
G3 Mic~wave	0.8670	0.2685	1.0000	0.2496	0.6949	0.1818	0.4235	0.0758
G4 Satellite	1.0000	0.3097	0.7600	0.1897	1.0000	0.2616	0.7190	0.1288

The model's overall synthesised results can be obtained using either of the two most common formulae that are implemented in the *SuperDecisions* (Adams and Saaty, 2003):

1. The multiplicative formula, in which the priorities of Benefits multiplied by the Opportunities are divided by priorities of Costs multiplied by Risks. That is:

$$\textit{\textbf{Multiplicative Score}} = \frac{B \times O}{C \times R}$$

The four BOCR vectors are thus combined by directly implementing the above formula and normalising the results. The most suitable alternative is the one with the highest value. However, the BO/CR method can only be used if BOCR merits are considered equally important, which may not always be the case. Thus, in order to allow for weight variation in BOCR so as to conduct sensitivity analysis later, one can use the subtractive formula described below which explicitly takes into account the BOCR priorities (b, c, o and r) displayed in Table 7.16.

2. The subtractive formula (*or additive-negative*), in which one can easily change the priority of one or more subnets while holding the relative priorities distribution among the other subnets constant to conduct sensitivity analysis. It uses the following formula for calculation:

$$\textbf{\textit{Subtractive Score}} = Norm(b \times B + o \times O - c \times C - r \times R)$$

Where: b, o, c *and* r are priorities of BOCR that were derived through pairwise comparison of the subnets with regard to the overall goal; and

Norm is the resultant's normalised value.

This formula shows that Costs and Risks scores are subtracted from the overall score. This indicates that the more costly or the more risky an alternative is, the more its negative contribution towards the total score is.

The model's final syntheses using both formulae described above given in Table 7.17 show that Microwave technology dominates under both formulae while Fibre comes second. This outcome confirms the earlier speculation that Microwave and Fibre are the top choices, with Microwave being the most favourable telecommunication backbone infrastructure technology in rural areas of developing countries.

Table 7.17 Final synthesised results

Formula	**BO/CR**		**bB+oO-cC-rR**
Alternatives	Unweighted	Normalised	Weighted
G1 Fibre	1.9100	0.2916	0.1841
G2 Power line	0.6369	0.0972	0.0075
G3 Microwave	**2.9461**	**0.4498**	**0.2605**
G4 Satellite	1.0570	0.1614	0.1090

The next section introduces the sensitivity analysis, which would essentially vary these judgements widely to determine the stability of the outcome.

7.3.5 Sensitivity analysis

Sensitivity analysis allows one to select any combination of independent variables to test the what-if scenario by changing the priority of one criterion, an entire cluster of criteria, or an entire subnet. Decision makers, through this process can discover how changes in judgements or priority about the importance of each criterion might affect the recommended decisions. For example, what if *Bandwidth* is much more important than all the other criteria in the Costs subnet? What if Risks are much more important than Costs? A decision model's outcome should preferably be fairly stable under small variations of the situations or environment (robustness). However, under certain significant changes in situation or environment, the model outcome should reflect them. In this model, sensitivity analysis using both a single independent variable and multiple independent variables were conducted.

For a single variable, a range of values, and the number of steps *n* can be selected to vary the input variable from the minimum of 0.0001 to the maximum of 0.9999 generating many points for all possible combinations of independent variable values (the range can be manually determined based upon one's information about the variable under study). The integer *n* can vary from 2 to a relatively large number. The default value of *SuperDecisions* is *n=6*. For instance, if there is a single independent variable selected, having a range of priority from 0.2 to 0.4 selected, with *n*=4 steps (i.e. 5 points of calculation), there will be alternatives' points plotted for the independent variable when its value is 0.2, 0.25, 0.30, 0.35 and 0.40 and spreading evenly across the x-axis (Adams and Saaty, 2003).

The experiments shown below indicate that *n*=20 for single variable analysis yields very smooth curves, *n* is inversely proportional to the priorities' perturbations because when *n* is increased to a very large value, the perturbations become very small. Hence, their impact towards the priorities are negligible. For example, in Figure 7.8 by setting *n*=20 and varying the Benefits priority from 0.0001 to 0.9999, where the interval for each step is $\Delta = (0.9999 - 0.0001)/(n-1) = 0.9998/19 = 0.05262$, one observes that its priority changes to $0.0001, 0.0001+\Delta, 0.0001+2\Delta, 0.0001+3\Delta \ldots 0.0001+19\Delta$. When varying the priority of Benefits, the relative priorities of other control criteria have to be maintained. For example, when the priority of Benefits subnet equals 0.32107, the priorities of Costs, Opportunities and Risks have to add up to 0.67893 while maintaining the relative proportion of their original priorities.

Figure 7.8 shows the changes in alternatives' ranking when varying the weight of the Benefits subnet and holding the other subnets constant. When the priority of Benefits subnet is 0.6 or higher, the ranking of the alternatives changes, so as Satellite becomes the second choice replacing Fibre. Whereas, when this priority gets lower than 0.1, Satellite becomes the least favourable option replacing Power line.

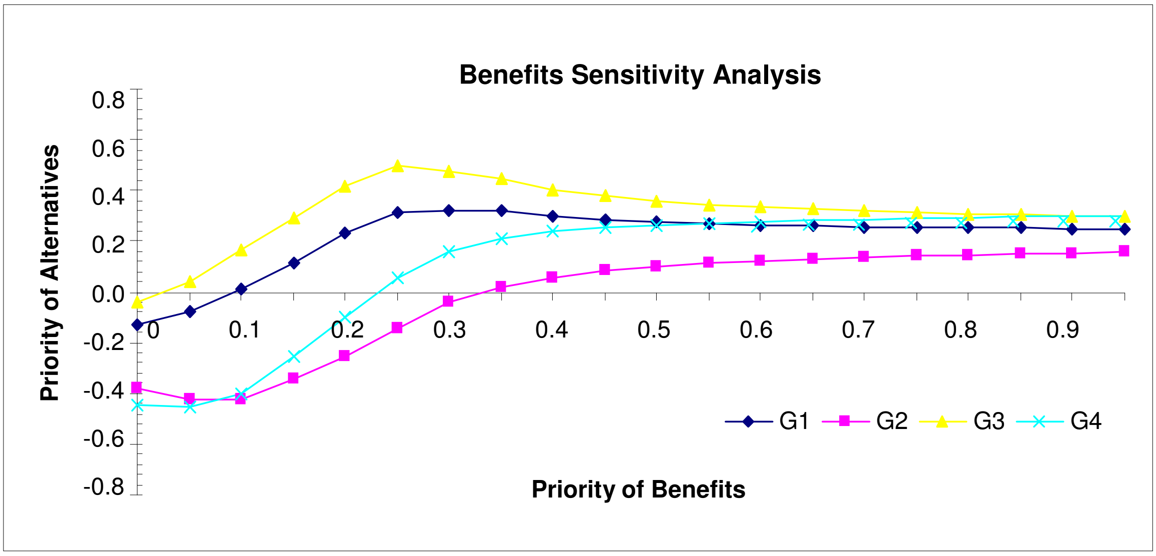


Figure 7.8 Sensitivity analysis for Benefits subnet

This seems logical, since Satellite is dominated in the Benefits subnet; hence, increasing its weight value will lead to improving its ranking among the other alternatives and vice versa. In addition, some of control subcriteria in the Benefits subnet, in particular, *Coverage* are notably dominated by Satellite.

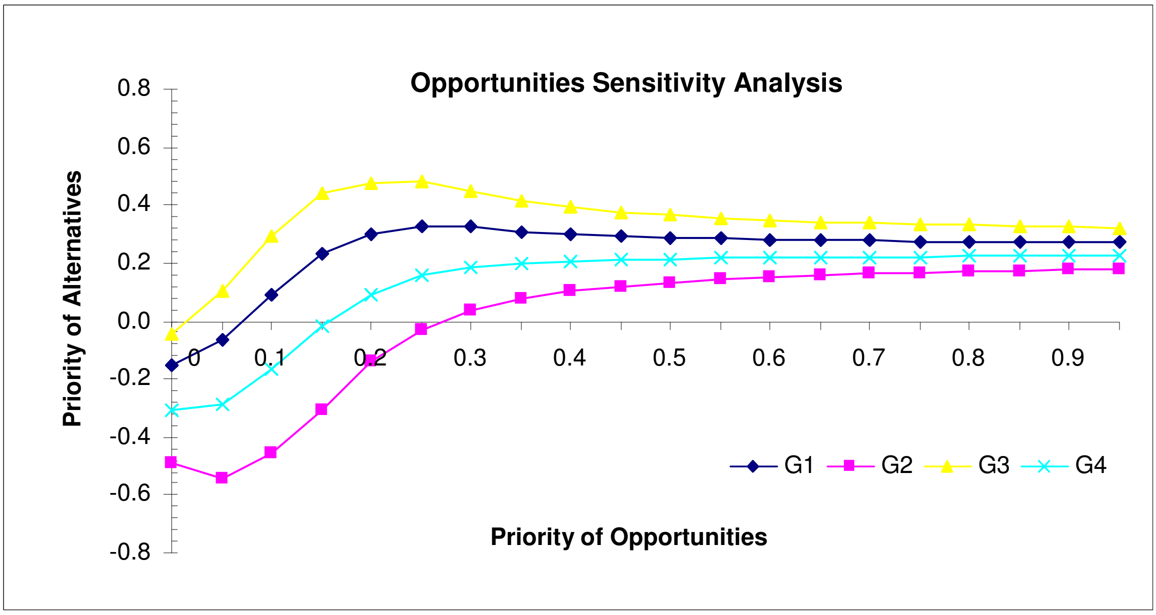


Figure 7.9 Sensitivity analysis for Opportunities subnet

Figure 7.9 above shows the sensitivity graph with the opportunities priority is set as the independent variable for Opportunities subnet, in which one can see that the results obtained by perturbing the priorities of this subnet are stable. This indicates that the Opportunities subnet model is insensitive to changes and thus the alternatives ranking are unchanged.

Figure 7.10 shows the changes in alternative ranking while changing the weights of Costs subnet. Similar to the Benefits subnet sensitivity analysis, Microwave is again perfectly dominating as it shows insensitivity to any changes in the Costs subnet followed by Fibre.

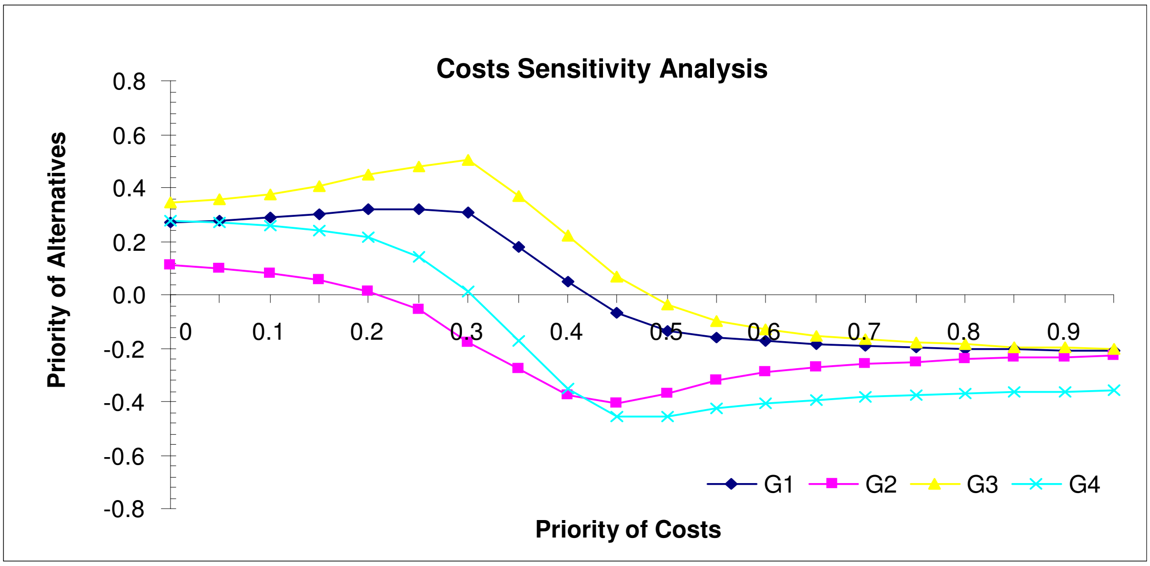


Figure 7.10 Sensitivity analysis for Costs subnet

However, when the Costs priority is increased to 0.42 or above, the alternatives ranking changes, and Power line becomes more preferred than Satellite. This is because Power line has the lowest cost under Costs subnet. Hence, when Costs become more important, Power line also becomes more preferred than Satellite. As long as the Costs priority is below 0.42, the ranking remains unchanged.

Results obtained for Risks are also stable as demonstrated in Figure 7.11. Microwave is almost perfectly dominating despite any changes in the Risks priorities. Hence, Microwave remains the most preferred alternative followed by Fibre.

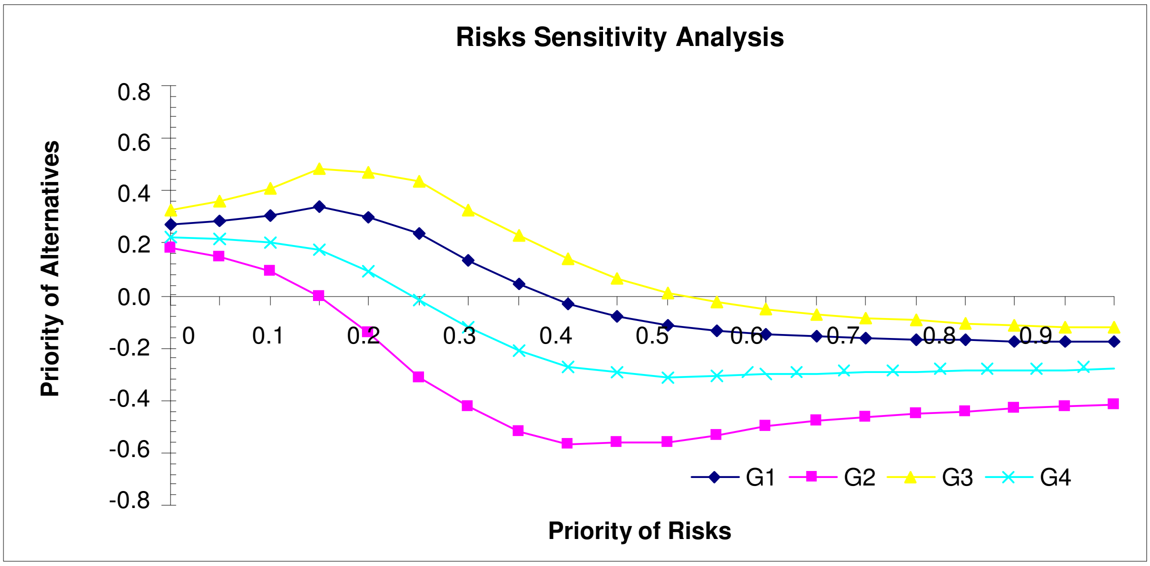


Figure 7.11 Sensitivity analysis for Risks subnet

Figure 7.12 illustrates the results of one of many possible multiple independent variables scenarios where combining benefits, opportunities, costs and risks subnets and changing their (b, o, c and r) weights causes a change in the priorities of the alternatives. For instance, along the vertical dotted line where b = 0.2202, o = 0.8016, c = 0.3745 and r = 0.2001, the priorities of the alternatives become: Fibre = 0.3070, Power line = 0.1260, Microwave = 0.3950 and Satellite = 0.1720. By inspecting the sensitivity graph, it is clear that Microwave technology dominates the entire spectrum. The fluctuations in the priorities of the alternatives as the weights of the BOCR models change (even with high priorities in costs and risks combined) keep the alternatives ranking unchanged indicating the robustness of the model and the reliability of its results.

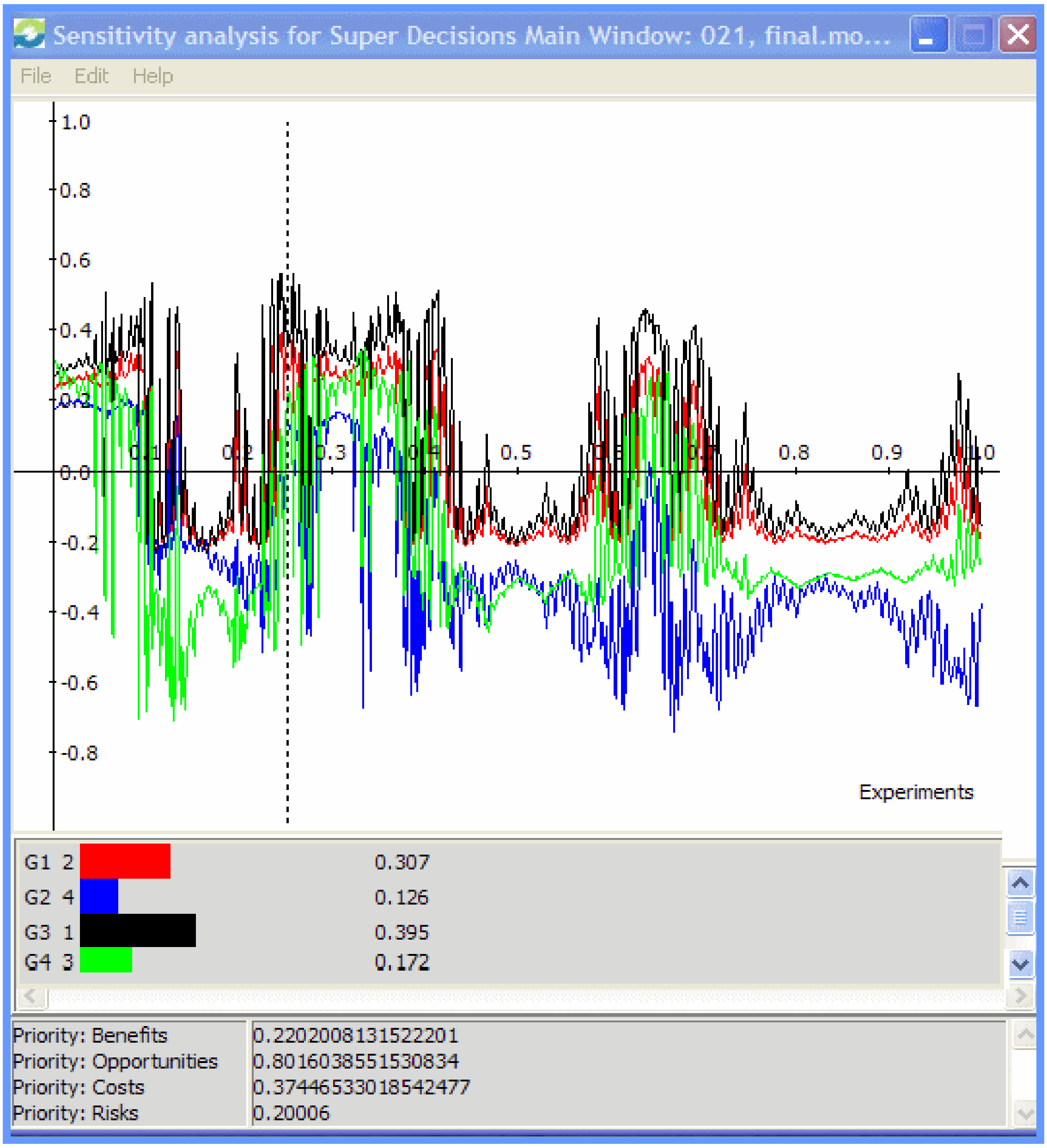


Figure 7.12 Sensitivity analysis for combined BOCR subnets

7.4 Conclusion

The deployment of rural telecommunication services is a complex activity, involving stakeholders with views that do not necessarily coincide. Due to the nature of disparities in rural development in most developing countries, the comprehensive framework proposed in this chapter for selecting a potential rural telecommunications backbone infrastructure takes into account the interests of the stakeholders, which further enhances the holistic approach articulated in this thesis.

In this chapter, the essential part of the proposed decision framework constituted of four separate multi-level networks: one each for the Benefits, Opportunities, Costs and Risks (BOCR). The top portion consisted of subnets and an overall goal element. The structure within each of these subnets consisted of clusters of factors, in which the control criteria/subcriteria are further grouped into clusters that are relevant to the sub-goal of the subnet. A qualitative approach was adopted in assigning a specific criterion to a category considering both the appropriateness and the importance of the criterion under a specific category. The bottom part contained a typical decision subnet, which is also an important part of the ANP decision framework that consists of three clusters: alternatives, decision makers, and other stakeholders. Consequently besides the 'Alternatives' cluster, which contained four technology options that were previously assigned, three types of decision makers were considered 'Management', 'Technologist', and 'Consultants'. They were characterised as 'fiduciary stakeholders' and placed under the 'Decision Makers' cluster. The 'Other Stakeholders' cluster contained three groups: 'Competitors', 'Clients', and 'Suppliers' classified as 'silent stakeholders'.

The strategic criteria and subcriteria in this model were identified from vast reading of the literature examined together with consulting several knowledgeable people on the subject area. Four primary strategic criteria were put forward by most of the experts. These are Public welfare, Infrastructure enhancement, Quality of service and Telecoms company (Telco) benefits. Each of these criteria included two subcriteria under them considered relevant to this problem. These strategic criteria/subcriteria were prioritised by conducting the usual pairwise comparisons of the AHP against each other and then calculating the eigenvectors. After completing the model structure, interactions among clusters as well as within clusters in the decision subnet were identified according to the connections developed. Then, the means described in chapter 5 were used to collect numerical input for this decision model. Once the pairwise comparisons were completed, three responses were obtained for each question. The geometric mean was computed for each pairwise question to derive the group average responses. The obtained group judgements were then used to perform necessary matrix algebra calculations.

The obtained results indicated that Satellite scored the highest in the Benefits subnet and, at the same time, it had the highest Costs and second highest Risks, which offset its overall ranking. Power line had the lowest scores in all subnets except in Risks, in which it scores the highest. Microwave scored the highest in Opportunities and had the lowest Risks but had the second highest Costs. Fibre scored the second highest in Opportunities and third in Benefits, Costs and Risks. Because benefits, opportunities, costs and risks were not equally important in such a highly socio-technical decision, their weights were derived using an AHP ratings model with respect to the strategic criteria/subcriteria. A rating model was then developed in which the BOCR were rated according to five intensities. The alternatives' priorities at the top level were synthesised by linking the priorities of the alternatives with the BOCR priorities, i.e. the b, o, c and r obtained from the rating model. The model's overall synthesised results were obtained using the two most common formulae implemented in *SuperDecisions.* The final syntheses using both formulae indicated that Microwave is the most preferred technology alternative within the context of the developing countries as it dominated under both formulae while Fibre came second.

Sensitivity analyses were also performed in this chapter. The sensitivity graphs showed the robustness of the obtained results. For example, when the opportunities priority is set as the independent variable for Opportunities subnet, it was observed that the results obtained by perturbing the priorities of this subnet are stable. This indicates that the Opportunities subnet model is insensitive to changes and thus the alternatives' rankings are unchanged. Similarly, sensitivity analysis results obtained for Benefits, Costs and Risks subnets indicated that Microwave is again perfectly dominating as it showed insensitivity to any changes in the Costs subnet followed by Fibre. By inspecting the sensitivity graph of one of many possible multiple independent variables, it was also clear that Microwave technology dominated the entire spectrum. The fluctuations in the priorities of the alternatives as the weights of the BOCR models change kept the alternatives' ranking unchanged, indicating the robustness of the model and the reliability of its results.

Providing a useful analysis framework and viable solutions to such an important and complex problem is the contribution of this chapter. The importance of the topic and the necessity for an all-inclusive analysis framework warrant this effort. It is assumed that this framework will enable decision makers of telecommunication companies to structure such a selection problem and reach proper decisions in this regard.

8. APPLICATION OF THE ANP MODEL – A CASE STUDY IN LIBYA

8.1 Introduction

Following many authors who stress the importance of practice for judging the theoretical results (e.g. Checkland, 1995), this chapter presents the findings of the experimental validation of the proposed ANP model for the selection of rural telecommunication infrastructure in the Al Qatrun area. This practical validation aims to evaluate the applicability of the generic ANP model, which was developed from literature and consultation with experts, as discussed in chapter six, in terms of systematically improving the group decision-making process of the selection process. To pursue this task, the author carried out an intensive 4-week field-study in Libya focusing principally on the main telecommunications infrastructure provider in Libya, namely: the General Post and Telecommunications Company (GPTC). The GPTC, which currently establishes, operates and maintains communication networks in Libya will act as a case study for the validation of the model.

Several data collection methods that were adopted in gathering relevant data needed for this study are discussed. Relevant information concerning GPTC rural telecoms systems was collected, with a particular focus on the systems that are suitable to provide backbone connectivity to rural areas. Appendix N engages in providing an overview of GPTC's infrastructure. The current selection process of telecommunications systems at GPTC is discussed and analysed from decision-making perspective. A number of problems were identified including criteria not clearly defined, decision process not systematic, slow decision making, etc.

The application of the proposed ANP model to a practical case study is presented, fulfilling the main contribution of this chapter. The case study involves the selection of rural telecommunications technology for securing connectivity to one of the southern country's remote rural town, namely Al Qatrūn. After setting up the workshop with a relevant focus group, the development of the model is discussed including setting selection criteria and alternatives, identifying dependencies among criteria, conducting pairwise comparisons and synthesising the results. The focus group reflection on the use of the ANP in such a technology selection processes is presented. The analysis of the post workshop questionnaire is also given together with some lessons learned from the process. The chapter concludes by giving a summary of the intervention.

8.2 Methods of data collection

The bulk of the information about rural telecommunications available in Libya tends to focus on the technological aspects only and therefore Libyan literature on the selection aspects of rural telecoms backbone infrastructure is scarce. In order to obtain accurate knowledge on the technology selection in Libya, the fact-finding techniques presented below have been implemented in gathering the relevant data needed for this study:

1. **Workshop:** In order to carry out a practical validation of the ANP model, it was necessary to set up a workshop with relevant personnel. As mentioned below, the responsibility for the deployment of rural telecoms infrastructure in Libya lies with GPTC who would initiate such an exercise. Hence, one formal workshop was arranged in collaboration with a focus group attached to GPTC, for the purposes of obtaining expert perspectives and judgements on rural telecommunications infrastructure selection. The workshop was held on the 20th August 2009 at the GPTC's planning department. The department's manager was extremely helpful and assisted the author is setting up the workshop. In particular, he was instrumental in getting the participants to attend and arranging the logistics for the workshop.

2. **Interviews**: GPTC departments involved in backbone infrastructures were visited and several interviews were conducted with their staff working at each site. Numerous informal interviews in the form of discussions and enlightenment were conducted with some relevant staff involved in the deployment of rural telecommunication infrastructure. In addition, two formal meetings were held with relevant experts from GPTC, with the aim of exploring the planning issues. Individual visits, as well as special investigations, were made to the rural telecommunications department in order to acquire reasonable and reliable information about the existing rural telecoms systems. Useful discussions were conducted with several key executives as well as staff technicians and that brought up valuable information concerning current problems. A summary of frequent failures and their causes concerning links of rural telecoms systems was also obtained.

3. **GPTC Documentation**: the available GPTC publications that include reports, surveys, previous studies, best practices, etc. were reviewed. Of particular interest was an evaluation study conducted in 2008 titled "Network Assessment and Recommendations". The study's main goal was to improve communications

between and among GPTC's customers by analysing the current network environment and understanding the issues encountered by GPTC and its customer base. It offers specific recommendations for updating and improving GPTC services, including connectivity to rural areas.

4. **Questionnaire**: Apart from the online questionnaires that were used for collecting pairwise comparison judgements from the participants of the workshop, two other questionnaires were designed. The first one was submitted to a number of personnel involved in the planning of rural telecommunications within GPTC. It included several questions covering various facts related to data required by this study. It was also sent to several relevant people attached to GPTC's owned service providers. This method yielded valuable information about the planning and design phase of rural telecommunication infrastructure and also the decision processes related to the selection of such infrastructure. The second one comprised a post workshop questionnaire aimed to gather the participants' feedback on the process. Both questionnaires including the questions that were asked are depicted in Appendix N.

8.3 Current rural telecoms technology selection process at GPTC

The provision of effective modern communication solutions to isolated rural areas and other underserved communities in Libya is obviously seen as a major challenge for GPTC. A contributory fact is that the Mediterranean coastline of nearly 1,900 kilometres and the Sahara desert are the country's most dominant characteristics. In addition, with an area of 1,760,000 square kilometres, Libya is fourth in size among the countries of Africa and fifteenth among the countries of the world.

This enormous geographic area is compounded by lack of transmission backhaul, difficult environmental and social challenges and lack of local engineering and business expertise. However, despite the challenges, the development of telecommunication infrastructure is the focus of the GPTC plans for massive investment over the next ten years. The demand for equipment and services relating to remote rural areas is growing in the framework of GPTC's master plan for networking strategic public services together with the private sector, in particular, foreign oil companies, which need appropriate infrastructure to carry out their projects.

In GPTC, which is the major telecoms service provider in Libya, the decision on rural telecommunications infrastructure selection is usually carried out and determined by its network engineering team, known as the Technical Facility Engineering and Construction (TFEC) group. It provides direction and approves all engineering and construction matters. It is made up of experienced engineering personnel who participate interactively in the design and engineering process. The group is composed of several different units, which include:

- Network Operations: It inherits the final constructed product and operations of the facility;
- Central Engineering Office: A planning and forecasting unit issuing the architectural and engineering drawings; and
- Equipment Engineering and Installation: Responsible for installing and powering up the electronic equipment.

Being the main interface for all its network connectivity and the primary group that designs new customer circuits and network builds, this team decides on a proposed telecommunications system, as a potential infrastructure technology. GPTC employs experienced personnel in satellite, microwave, and optical fibre technologies and it is responsible for evaluating new technologies that improve network reliability and customer satisfaction. The proposed system will then be placed on a shared computer network, to encourage criticisms, corrections, and/or comments. It is retained until the comments/criticisms from colleagues are exhausted. After receiving and consolidating comments, the outcome is revised in preparation for the final report on the selection process to be submitted to the team leader. Once approved, it then becomes ready to be considered for deployment. A copy of the report is to be sent to the purchasing department to initiate the tendering process. This department will send out an 'invitation to tender', with copies of the technical specifications to potential vendors. After receiving all proposals from vendors, a contracting phase commences to evaluate and select the most suitable offer.

It was noted during the interviews with some staff members attached to the rural telecoms department that currently there is no systematic technology selection methodology in place to guide them to reach objective decisions in the selection process. Furthermore, from the current selection of rural telecommunications infrastructure in GPTC described above, a number of problems are identified, which include:

- **Undefined selection criteria**

  The selection criteria are not clearly defined because engineers tend to focus on the technical factors based on their past experience of requirements of a telecommunication system and the relevant international engineering standards. Although such factors cover a lot of details such as technical features/characteristics, compatibility and flexibility, etc., criteria are not explicitly defined and may not be suitable to address the situation in rural environments. The emphasis given to the technical aspects tends to ignore other important factors for rural settlements, such as social, environmental, political, economic constraints, etc. Besides, there could be a disagreement or request for change to the criteria for comparison by the selection team members. A chance of missing some major criteria or important issues related to rural areas is another possibility.

- **Unsystematic selection process**

  The problem identified preceding this, in turn, affects the subsequent phases of assessment. Moreover, despite the complexity and the numerous diversified criteria to be considered, as explained in Appendix A, the group decision-making phase usually does not utilise any decision-making tool or mathematical technique to facilitate the decision process of selection.

- **Difficulty in deriving common consensus**

  In addition, there is no defined approach in making the final decision. Usually the recommendations of some influential members of the selection team may be considered but the final decision should get agreement from all members in order to get their commitment in the system rollout. Thus, another problem here is the potential of bias towards recommendations of some who may play an important role in the decision and may influence other team members in their choice.

- **Slow decision making**

  Consequently, the difficulty in getting common consensus may slow decision-making. Since the rural telecoms infrastructure selection is complex and the list of criteria is long, the decision makers need to use their own analytical thinking to come up with a decision. Quiet often, the decision makers will focus on the criteria that they consider as most important, but team members have different concerns. For example, engineers will focus on technical features while economists will focus on cost. Some times intuition will be used and personal bias can also affect decisions. Thus, it is difficult for group members to arrive at a final decision, which leads to slow decision-making. In cases were the selection decision was not agreed upon by all members, the case will be delayed for quite a long time causing a delay in service launch. It can be seen that the failure to get consensus and slow decision making can have an adverse effect on the company. The minor effect is a delay of service launch and that manpower has to be spent to revisit the case and make the selection again.

8.4 The selection of telecoms technology for Al Qatrūn rural area

The following case study revolves around the selection of rural telecommunications backbone infrastructure for securing connectivity to a remote rural town in southern Libya called Al Qatrūn. It has been chosen for this study because it was on the GPTC list that includes remote rural towns to be connected with the rest of the country within the current five-year plan (2005-2010). It has a potential for economic development, especially in terms of tourism and other allied business opportunity.

8.4.1 Characteristics of the target area

The principal study area ‘Al Qatrūn’ is an oasis crossroads town in south western Libya, specifically located on the main road to Chad and Niger as shown in Figure 8.1. It lies within the geographical coordinates: 24°57′50″N 14°38′55″E with an average elevation of 518m. It is a typical setting in Murzuq municipality and lies further south of Murzuq city in the southwest of the country. It is distanced approximately 230 km from the Sabha municipality, the third main district in the country, which is located in the centre of the country, considered the most important city of southern Libya, and is where the Sahara Desert begins. Neighbouring villages include Wadi Atba, and Tragen.

Figure 8.1 Map of Libya
(Source: www.about.com)

Al Qatrūn is situated approximately 130 kilometres south of the modern town of Germa. Of particular interest to tourists in this region is the medieval town of Old Germa, which is built on the remains of ancient Garama, the capital of the Garamantes tribal confederation, which was a major power in southern Libya between about 500 BC and 500 AD. Several other popular tourist spots including lakes and oasis are scattered in the nearby area. The total population of the Al Qatrūn is less than 10,000 with an approximate density of 28 per 7 km radius (Libya census, 2006) and the population granularity is mostly a mixture of ethnicities. The town has varying land topography and the most important economic sectors in this area are agriculture and tourism. The lack of basic infrastructural services tends to restrict economic development. In deploying a new infrastructure technology for such areas, it should be realised that a town and its surrounding rural areas are a complex arrangement, meaning that a single simplistic view of a town is irrelevant. Rural telecommunications is one of the key ingredients in the integrated economic and social development. Thus, in selecting infrastructure, the author believes that it is necessary to examine the issues associated with telecommunications and rural development discussed in chapter two from different perspectives including all relevant stakeholders.

8.4.2 Development of the ANP model

This section uses different techniques such as brainstorming (to explore and discuss issues associated with the selection of rural telecommunications technology for Al Qatrūn area), prioritisation of criteria using ANP and implementation of *SuperDecisions*. The purpose of this intervention is to provide an environment for learning to the GPTC participants by empowering them to embrace such effective analytical decision tools and motivating them to acquire adequate knowledge for the improvement of rural telecommunications infrastructure decision-making process.

The decision process of this model was simulated using an experimental investigation involving a group of 15 personnel. The participants included representatives from the network engineering team within the GPTC. The persons selected had the most senior positions among their colleagues in the company and were equipped with various backgrounds and experiences. They had experience in related technology selection problems and were actually involved in making such critical rural decisions. At the beginning, the participants were given a short presentation by the author explaining the used methods as well as the aim and objectives of the study.

The presentation was followed by a general discussion on the various issues that may influence the provision of telecommunication services in rural areas. As abovementioned, currently there is no systematic technology selection methodology in place to guide telecoms planners to reach proper objective decisions in the selection process. It was noticed that the participants were not very familiar with the ANP. However, some of them had come across some AHP models in the literature.

8.4.2.1 Setting selection criteria and identification of alternatives

The author acted in the role of a facilitator and interacted with the participants to acquire their knowledge and expertise related to the selection and deployment of telecoms technologies. The participants recognised the confusion and frustration service providers, developers and the community suffer during the deployment of such technologies, because the process is not linear and takes a long time for consensus and approval. They are aware that before the rolling-out of rural telecoms infrastructure, there should be proper planning, which has to be transparent and inclusive.

The participants were then asked to explore the list of the selection criteria for the problem, which was compiled in Chapter 5 (described in Appendix A) and asked for feedback about it. The list included possible criteria that need to be considered when selecting telecommunication infrastructure technologies for the Al Qatrūn town. The author clarified the issues involved during the group discussions and noticed that such a broad diversified list of criteria is not common to some participants. This is mainly owed to the technological background of those participants. Of particular note and interest to the workshop participants were the criteria such as ‘remoteness of area’, ‘parallel infrastructure’, ‘terrain topography’, ‘climatic conditions’, ‘security of physical infrastructure’, ‘availability of skilled technicians’, ‘community of interest’ ‘rights of way’ and ‘population density’ that are more applicable to remote rural areas and which adds to the complexity of deciding the most appropriate backbone technology for the particular surroundings.

With the overall goal being the ‘selection of telecommunications technology for the Al Qatrūn area and based on the discussions with the participants and in helping the group achieve a consensus, the list of criteria was thought to suit the target area. The group therefore agreed on the list of the criteria (i.e. factors) which the new backbone technology must satisfy, including specific details of the technical, regulatory, environmental, economic and social aspects desired by the company. The clustering of the criteria remained unchanged as was the case in chapter 5.

Following further discussions on the Al Qatrūn remote rural area and upon examination of the possible technology alternatives, the focus group decided that only three of the adopted backbone infrastructure technologies identified in chapter 5 are applicable to the Al Qatrūn area. Hence, the Power Line Communication alternative was unanimously discarded from the model because such a technology solution is not yet implemented by GPTC anywhere around the country. The remaining alternatives were evaluated using a group decision process based on ANP. They are recoded as G1 'Fibre', G2 'Microwave' and G3 'Satellite'. The description of the selection criteria and the alternatives are not presented here because they have already been discussed in Appendix A.

8.4.2.2 Identifying dependencies among criteria

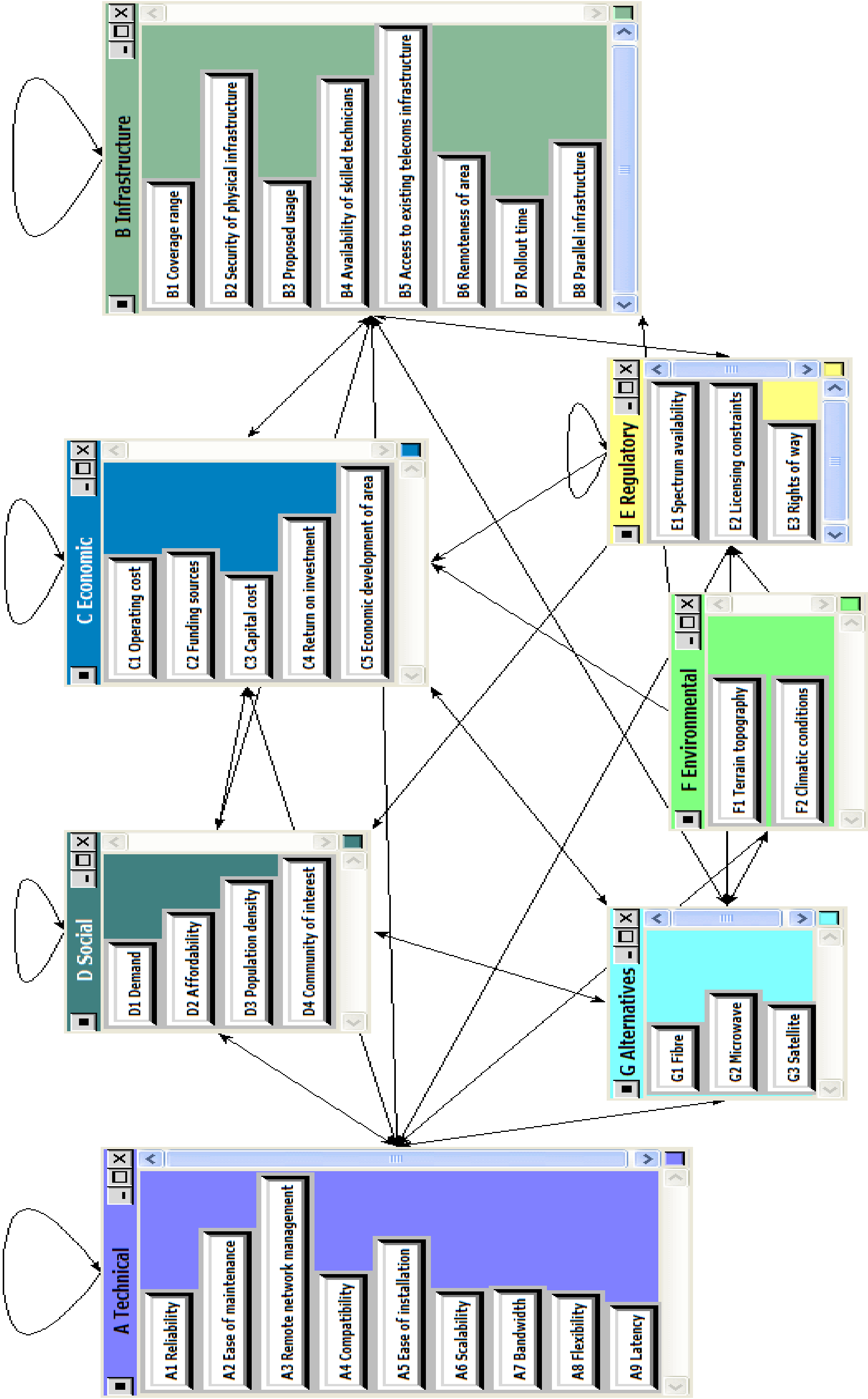
After structuring the decision problem, the next step is to examine the dominance of influence among criteria. In order to fulfil this task, the dependency questionnaire developed in chapter 6 was distributed to the participants. To expedite the process, the participants were divided into five groups of three and each group was given a questionnaire and requested to discuss and identify any possible dependencies among any pair of the criteria. The participants were reminded that their responses had to be in reference to the selection of rural telecoms technology for the Al Qatrūn area. After the completion of the questionnaire, one completed questionnaire was collected from each group. The majority rule was then used to aggregate the responses into a single matrix shown in Table 8.1, which was developed using a zero-one matrix of criteria against criteria using a binary value of 1 and zero (Saaty, 2006).

A majority condition of 3 out of 5 (3/5) groups of experts' consensus (i.e. 60%) was considered as a minimum requirement for any entry that indicates the existence of a direct relationship among criteria. Table 8.1 shows all possible connections, where the entries a_{ij} can take the value of 1 to signify dependence of one element on another, and zero otherwise. Subsequently, a pairwise comparison matrix will be constructed only for the dependent criteria.

Table 8.1 The dependency matrix showing all connections among elements

Clusters	Criteria	w.r.t																															
		A1	A2	A3	A4	A5	A6	A7	A8	A9	B1	B2	B3	B4	B5	B6	B7	B8	C1	C2	C3	C4	C5	D1	D2	D3	D4	E1	E2	E3	F1	F2	G1	G2	G3
A	A1		1	1	1	0	1	1	1	0	0	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
	A2	0		1	1	1	0	0	1	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
	A3	1	0		1	0	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	A4	0	0	0		1	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	A5	0	0	1	0		0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
	A6	1	0	0	1	1		1	1	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	1	1
	A7	0	0	0	0	0	0		0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	1	0	1	0	0	0	0	1	1	1
	A8	0	0	0	1	0	0	0		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1
	A9	0	0	0	0	0	0	1	0		0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
B	B1	0	0	0	0	0	0	0	0	0		0	1	0	1	1	0	0	0	0	0	1	1	1	0	1	1	1	0	0	1	1	1	1	1
	B2	0	0	0	0	0	0	0	0	0	0		0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	B3	1	0	0	0	0	0	0	0	0	0	0		1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	1	1
	B4	0	0	0	0	0	0	0	0	0	0	0	0		0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	B5	0	0	0	0	0	0	0	0	0	0	0	0	0		1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	B6	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	1
	B7	0	0	0	0	1	0	0	0	0	1	0	0	1	0	1		1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	B8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0		0	0	1	0	1	0	0	0	0	0	0	0	1	0	1	1	1
C	C1	1	1	1	1	0	0	0	0	0	0	0	0	1	0	1	0	1		0	0	0	0	0	0	1	0	1	1	0	1	1	1	1	1
	C2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0		0	1	1	0	0	0	0	0	0	0	0	0	1	1	1
	C3	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	1	1	1	1	1
	C4	0	0	1	1	0	0	0	1	0	1	0	0	0	0	0	0	1	1	0	1		1	1	1	0	0	0	0	0	0	0	1	1	1
	C5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0		0	0	1	0	0	0	0	0	0	1	1	1
D	D1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0		0	1	0	0	0	0	0	0	1	1	1
	D2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	1	0	0	0	0	0	1	1	1
	D3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	1	1	1
	D4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0		1	0	0	0	0	1	1	1
E	E1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	0	0	0	1	1	1
	E2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	1	1	1
	E3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0		1	0	1	1	1
F	F1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	1	1	1
	F2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	1	1
G	G1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
	G2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
	G3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			

According to the connections identified in Table 8.1 above, the network structure of the decision process was then constructed using *SuperDecisions* as depicted in Figure 8.2. The network model displays the clusters and their inner and outer dependencies connections, in which it is clear that excluding the environmental and alternatives clusters, all remaining clusters have inner dependency loop. This indicates that the elements in each of those clusters depend on each other with respect to the goal.



8

Figure 8.2 The network model with connections among elements/clusters

8.4.2.3 Pairwise comparisons and weights

The network structure developed above contains 84 judgement matrices that include a total number of 542 pairwise comparison questions, it would be a time consuming process to come up with consistent pairwise comparison matrices, which would be acceptable to all members for each single criterion. For this purpose, answering the pairwise questions by a traditional hardcopy questionnaire is thus impractical. Therefore, under these constraints, the only reasonable solution is to modify and reutilise the online questionnaires, which were introduced in chapter 6 and shown in Appendix G.

In order to ensure the reliability of the online surveys and to avoid any ambiguities, they were tested immediately after they were designed. A pilot test that involved several experts was conducted before uploading them online. This process was repeated automatically with all subsequent questionnaires, which were also optimised in line with the experience gained from the interaction with the experts and their feedback. Eventually, the links of the questionnaires were sent to all participants who despite some difficulties were more comfortable (after the dependency assessment exercise) in answering the pairwise comparison questions by means of their internet-connected laptops.

The main difficulty encountered in getting responses from experts through online surveys is the length of time required to fill them in. Hence, one of the notable respondents' comments received at an earlier stage of the research is that the golden rule to be taken in mind when asking experts, is to set a time limit for the questionnaire, so that it will not take more than 10 minutes at most for the respondent to complete. The author had accordingly designed all succeeding surveys in accordance with this comment. This suggestion was deemed to be very beneficial during the process of collecting pairwise comparison judgments. Some participants had difficulty in interpreting some of the questions. However, after some clarifications by the facilitator, they were able to answer the pairwise questions individually according to their expertise.

Once pairwise comparisons were completed, five responses were obtained for each question. The geometric means were computed using Excel in order to aggregate individual judgements into a representative group judgement for each pairwise question in order to reveal the aggregated group judgements. The Assess/Compare command of the *SuperDecisions* was then used to enter the obtained group judgements and initiate the comparison process. An example of the used comparison questionnaire mode is shown in Figure 6.4, chapter 6.

The *SuperDecisions* computations command has been used to perform necessary matrix algebra in relation to the creation of the three supermatrices associated with this model as shown in Appendix M. Table M1 illustrates the unweighted supermatrix that contains the local priorities derived from pairwise comparisons throughout the network; they can be read directly from this matrix.

In such a problem, it is essential to know the importance of the clusters to which the elements belong because the final priorities depend on that. As the clusters in this network are not equally important, they were also compared. Hence, the experts were asked to compare the clusters in order to establish the cluster matrix weights. Each cluster was taken in turn as the parent cluster and pairwise compared with all the clusters it connects to for importance with respect to their influence on it. An example of the formulated cluster comparison questions is: Which of these aspects influences the selection of the alternatives in rural areas more, Technical or Social?

The resultant cluster matrix is shown in Table 8.2. An example of the interpretation of the priorities shown in the table, from the last column, one can observe that social (0.3001) and technical (0.2281) aspects have the most impact on the three alternatives with respect to this model. The values in the cluster matrix are used to produce the weighted supermatrix shown in Table M2 and Table M3. The limit supermatrix is reached by raising the weighted supermatrix to large powers by multiplying it times itself.

Table 8.2 The cluster matrix

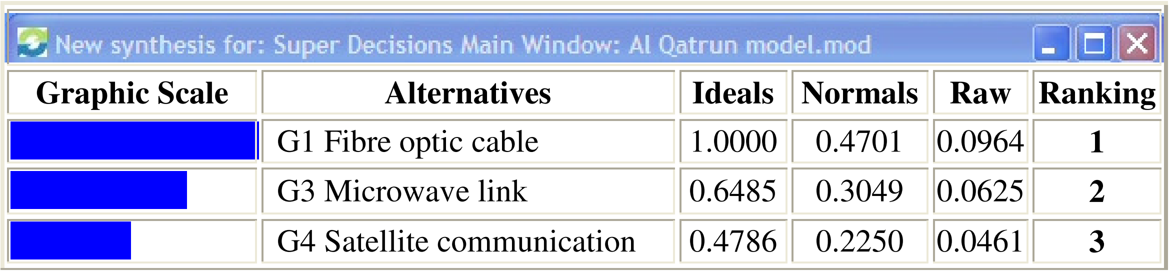
Cluster	**A**	**B**	**C**	**D**	**E**	**F**	**G**
A Technical	0.1592	0.2566	0.1862	0.0902	0.1580	0.3145	0.2281
B Infrastructure	0.2955	0.2302	0.1503	0.0979	0.1659	0.3792	0.1712
C Economic	0.1592	0.0694	0.1018	0.0442	0.1730	0.0846	0.0461
D Social	0.2885	0.2972	0.5313	0.3393	0.3952	0.0000	0.3001
E Regulatory	0.0000	0.0959	0.0000	0.0000	0.0638	0.1353	0.1410
F Environmental	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1135
G Alternatives	0.0976	0.0508	0.0303	0.4284	0.0442	0.0864	0.0000

The *SuperDecisions* was implemented to perform such complex calculations. It first tests the stochastic matrix (W) for irreducibility, and unless there is cyclicity for which the Cesaro sum would be calculated, it obtains the outcome for primitivity as the limit powers of W. If the irreducibility fails, it again raises W to large powers (see, Saaty 2010). With the priorities normalised by the cluster, the columns become all the same; the global priorities for all elements can be read from any column as shown in Table M3.

8.4.2.4 Final results and discussion

Figure 8.3 presents the final results 'global preferences' for alternatives which were obtained using *SuperDecisions* 'Synthesis' command. The results are displayed in three different ways: The Raw column illustrates the priorities obtained from the limiting supermatrix; the most usual form used to report priorities is presented in the Normals column in which the results are normalised by cluster weight and finally the Ideals results are obtained by dividing the values in either of the other two columns by the largest value in that column.

These results indicate that the Fibre Optic cable technology is the most preferred alternative for Al Qatrun rural area with a priority of 47.01%, Microwave has 30.49% and the least preferred technology among others is Satellite with a priority of 22.50%. According to the 'Ideals' priorities; Fibre has a priority of 1.0, i.e. 100%, so Microwave is 64.85% as suitable as Fibre and Satellite is 47.86%.


New synthesis for: Super Decisions Main Window: Al Qatrun model.mod

Graphic Scale	Alternatives	Ideals	Normals	Raw	Ranking
	G1 Fibre optic cable	1.0000	0.4701	0.0964	1
	G3 Microwave link	0.6485	0.3049	0.0625	2
	G4 Satellite communication	0.4786	0.2250	0.0461	3

Figure 8.3 Final results for Al Qatrun model as obtained from *SuperDecisions*

The *SuperDecisions* priorities command has also been used to produce the priorities shown in Table 8.3. It contains the relative importance of all criteria considered in the model. For example, under the limiting priorities' column, one can observe that the most important factors among all are 'Demand' with a priority of 5.89% followed by 'Operating cost' with 5.87%.

According to the Normalised priorities column, the most important criterion is 'Terrain topography' with a priority of 70.38% followed by 'Spectrum availability' with 53.58%. Among the technical criteria; compatibility, reliability and remote network management criteria have the highest priorities of 18.02%, 17.82% and 12.96% respectively. Rollout time and return on investment factors are regarded the most important within infrastructure and economic clusters with priorities of 26.03% and 33.44% respectively. The relative importance of all other criteria considered in the model can be seen in Table 8.3.

Table 8.3 The relative importance of the criteria

Cluster	Criteria	Priorities (%)	
		Normalised	Limiting
(A) Technical	(**A1**) Reliability	17.82	5.23
	(**A2**) Ease of maintenance	9.90	2.91
	(**A3**) Remote network management	12.96	3.80
	(**A4**) Compatibility	18.02	5.29
	(**A5**) Ease of installation	12.57	3.69
	(**A6**) Scalability	10.31	3.03
	(**A7**) Bandwidth	11.21	3.29
	(**A8**) Flexibility	3.04	0.89
	(**A9**) Latency	4.19	1.23
(B) Infrastructure	(**B1**) Coverage range	24.74	4.42
	(**B2**) Security of physical infrastructure	2.51	0.45
	(**B3**) Proposed usage	10.85	1.94
	(**B4**) Availability of skilled technicians	1.28	0.23
	(**B5**) Access to existing telecoms infrastruc.	24.28	4.34
	(**B6**) Remoteness of area	4.01	0.72
	(**B7**) Rollout time	26.03	4.64
	(**B8**) Parallel infrastructure	6.33	1.13
(C) Economic	(**C1**) Operating cost	45.88	5.87
	(**C2**) Funding sources	8.09	1.03
	(**C3**) Capital cost	11.03	1.41
	(**C4**) Return on investment	33.44	4.28
	(**C5**) Economic development of area	1.56	0.20
(D) Social	(**D1**) Demand	42.50	5.89
	(**D2**) Affordability	25.01	3.46
	(**D3**) Population density	3.78	0.52
	(**D4**) Community of interest	28.71	3.98
(E) Regulatory	(**E1**) Spectrum availability	53.58	1.78
	(**E2**) Licensing constraints	30.29	1.01
	(**E3**) Rights of way	16.13	0.54
(F) Environmental	(**F1**) Terrain topography	70.38	1.64
	(**F2**) Climatic conditions	29.62	0.69

In order to analyse the effects of variations in judgments on the stability of the final outcome, one can perform sensitivity analysis. As was the case in section 7.3.5, one can generally do sensitivity with respect to the BOCR subnets individually or together in the top level. However, in standard ANP networks in order to conduct sensitivity analysis with respect to the judgments, priorities, or the entries in the supermatrix, one needs to pick an element that corresponds to the goal element. Then, picks a 'with respect to' element that is connected from it (any linked element), then gets the priorities of the alternatives as the 'with respect to' element which changes its priority. Thus, sensitivity analysis in standard networks is very hard to interpret and very time consuming process. In other words, sensitivity analysis is different in a network than it is in a hierarchy, where one picks an element (e.g. the goal), then changes the priorities of a criterion that is connected to the goal and examines the change in the priorities of the alternatives (Tosun et al. 2007).

To overcome this issue, the *SuperDecisions* developer is currently updating the package exploring different ideas concerning performing sensitivity analysis in the standard ANP networks. The sensitivity analysis in the new version will be different from how it is done in a hierarchy that users have used in the past. It involves conducting experiments by changing the priority of an element of interest (in the weighted supermatrix) by, for example, 10% up then 10% down, and observing if and how the outcome of the alternatives is affected. Then increasing the priorities change by 20%, 30% and so on. It has to be done through an iterative process stepping through all the elements individually, and in combination, to find out which ones, when changed, actually have an effect on the final answer.

Apart from the great deal of time allocated to planning and making arrangements, this case study took one month of actual research, interviewing officials and experts and thinking to complete. The author believes that the time was worth it. Without ANP, such a decision would have entailed countless hours analyzing and deducing the influence of the intangible factors, for which, so far, there has been no means to converge them into a single, rational and justifiable outcome. For further discussion on the ability of the ANP in dealing with intangible factors, one can refer to sections 3.3.3 and 3.4. The use of the ANP in this case study is therefore both useful and inspiring, in terms of aiding planners of rural telecoms infrastructure in managing the complexity related to decision-making processes of rural telecoms projects. More discussion in this regard can be found in the reflection section 9.4.

In the case of Al Qatrūn, the absence of its past statistical data, containing technical and economic related factors etc., complicated the process of matching the parameters of an engineering problem to the available solutions, thus becoming a challenge to the telecoms engineer in this particular selection phase. Statistics is a critical tool of the sciences for it is used to gain a reliable representative sample of population. It affords to see the significance of data and the relationship among seemingly unrelated phenomena to perceive future possibilities or determine what may have eventuated in the past. Unfortunately, even the current data for the Al Qatrūn area are not available and it was learned that they are to come once the 2010 census has been finalised. They will then provide more information that would allow intensive analysis of the state of telecoms infrastructure provision in this remote town and permit evaluation of its socio-economic impact. Although this falls outside the scope of this thesis, the author will continue with it as an on-going project and carry out an analysis. Recommendations can then be made to the telecoms infrastructure providers and policy makers.

The results shown in Figure 8.3, which were obtained through direct interaction with GPTC staff members, reveal that the most significant conclusion in respect of the telecoms backbone technologies for the Al Qatrūn applications is the direct investment by the GPTC, which is a government owned operator, in the provision of 'open access' fibre optic cable backbone through a public/private consortium. It is most likely the main motive behind selecting optical fibre backbone for trunk transmission to such remote rural areas. The need to roll out fibre backbone to the Al Qatrūn area and allow access to it in appropriate ways are key prerequisites for the successful implementation of an Information and Communication Technology (ICT) policy. For other areas with specific constraints, other technology solutions could be investigated. Once fibre is available to the Al Qatrūn rural communities, access to high bandwidth is secured, thus further mechanisms can be designed to extend the services and benefits to the users.

8.5 Reflection of the workshop's participants on the ANP

A post workshop session online questionnaire was designed and used to gather information on the participants' satisfaction with respect to:

- The ANP approach followed for the selection of rural telecommunications infrastructure;
- Importance and relevance to the problem under investigation; and
- Aptness of the processes of identification of the dependencies among criteria and pairwise comparison.

The questionnaire was prepared in line with those used by DeSanctis et al. (1990) in group decision support systems (GDSS). The feedback helped to validate the ANP model used for the selection process. A screenshot of the questionnaire is depicted in Appendix N, Figure N.4 and the participants' responses illustrated in Table N.2. The 5-point Likert scale (used in section 5.3) was modified and used to obtain a range of participants' opinions with respect to each particular question. The values of the scale were verbally interpreted as follows: '1 = not at all', '2 = to a little extent', '3 = to some extent', '4 = to a great extent' and '5 = to a very great extent'. An analysis of the participants responses together with a graphical representation of the results are given in Table 8.4 and Figure 8.4 respectively.

Table 8.4 Participants' responses to the post workshop questionnaire

		Questions	1	2	3	4	5	6	7	8	9
		Mean	**4.13**	**4.19**	**3.81**	**3.75**	**3.69**	**3.81**	**3.94**	**3.31**	**4.25**
% of each intensity occurrence											
Intensities	(1) Not at all		0	0	0	0	0	0	0	0	0
	(2) To a little extent		0	0	0	7	7	13	13	33	13
	(3) To some extent		27	13	27	33	47	27	27	33	27
	(4) To a great extent		13	40	60	40	33	47	40	13	20
	(5) To a very great extent		60	47	13	20	13	13	20	20	40

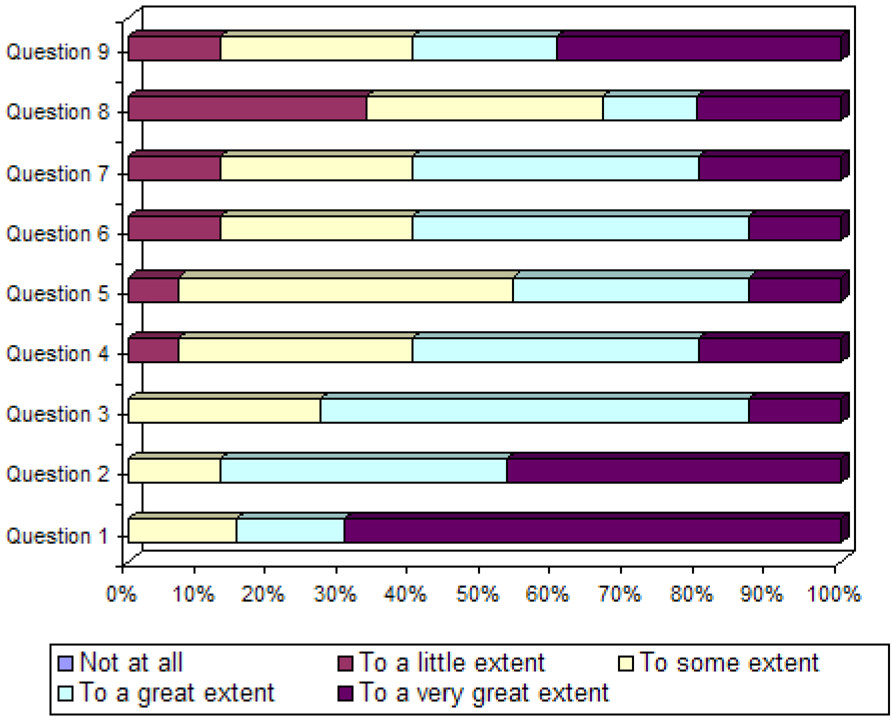


Figure 8.4 A graphical representation of the participants' responses

The Overall results can be viewed as reflecting a very positive attitude towards this workshop as the means of 8 out of 9 questions exceed 3.5 on the 5-point scale and in 3 out of 9, they exceed 4. Analyses of the responses of all questions are given below (note that concerned questions are shown in *italics*).

The most frequent answer to question 1 and 2 "*Do you think the adopted criteria, their clustering and the development of the network made the selection process easier?*" and *"Did you find the pairwise comparison easy to follow?"* were "to a very great extent". These questions related to certain aspects of the applied method. The mean values were 4.13 and 4.19, which are the third and second best, respectively as indicated in Table 8.4. It shows that the network structure was useful and the pairwise questions asked were straightforward and understandable.

The results of question 3 *"Do you think that the Analytic Network Process (ANP) is a good technique for prioritisation of criteria and ranking of the alternatives?"* show that more than half of the respondents answered "to a great extent" indicating their interest in the ANP. They were also positive about question 4 *"Do you think the Analytic Network Process (ANP) method used in the workshop helped you to gain a better understanding of the problems associated with rural telecommunications infrastructure selection?"* in that they felt that the ANP allowed them to become more informed about the problems encountered in the selection of rural telecoms technology.

In terms of question 5 *"Did you find the whole process valuable?"* one participant (7%) answered "To a little extent" while 47% answered "to some extent". The answers of question 6 "*Do you have confidence in the result obtained though the ANP?*" increases substantially reaching 47% for "to a great extent" reflecting the level of the participants' satisfaction and confidence in the obtained alternatives ranking.

In respect to question 7 "*Did you think group decision-making is more useful than individual decision-making in problems associated with rural telecommunications infrastructure selection?*" 40% of the responses were "to a great extent". However, the results of question 8 *"Do you think the time spent on the workshop was sufficient to attain its purpose?"* scored higher in "to a little and to some extent" than "to a great or very great extent" Understandably, this could perhaps be owed to the limited workshop time, technical background of the participants who were not familiar with such techniques and the lack of formal training in such a method. Finally, the highest mean value of 4.25 among all the questions was related to question 9 *"Do you find this workshop useful?"* as 40% expressed an opinion of "to a very great extent"

In summary, one can conclude that the questionnaire demonstrated the participants' satisfaction with the new applied ANP approach for the selection of rural telecoms technologies and also acceptance of the obtained results.

8.6 Lessons learned

This chosen study provided an opportunity to uncover issues, concerns and challenges that could be encountered during the project lifecycle. Conducted with dedicated time and efforts, the author was afforded an interim view of what has gone, as well as what needs to be improved for successful completion of the project. This review resulted in lessons learned from the Libyan experience as follow:

- During the workshop session, the relevance of this undertaking became transparent to the participants. Some acknowledged the ease in providing pairwise comparisons judgements. Also, the involvement of several staff members and their inputs, which reflected a diversified expertise, were recognizable during the brainstorming session;
- In terms of the responses to the dependency questionnaire, the participants think that such a process can be viewed twofold. They stated that considering all dependencies in the structure enlighten the process but on the other hand increases the number of pairwise comparisons, which entails more time and efforts;
- Despite the intricacies centred around the non-technical issues, the participants were agreed that their pairwise comparison judgements to select the most appropriate telecoms backbone technology for the Al Qatrūn area, is interesting, useful and a learning exercise. They acknowledged that this kind of input is relevant from a technology selection point of view and highlighted the complexity of the problem where one also needs to consider other ‘softer’ issues;
- The participants had a fairly good idea of how to determine whether the selection and provision of rural telecommunication technologies constitute an improvement or not. The facilitator was then asked the question “What will be the outcome of this workshop?” The facilitator explained that since this workshop is carried out within the GPTC premises, a report of the findings will be submitted to them and that it was hoped that the issues raised will be taken into consideration in the choice of rural telecoms technologies. The participants were confident that they were involved in a such a productive exercise;
- The information obtained during the field study indicates that many schools and clinics in the Al Qatrūn area have telephone and internet services that are unreliable. This is due to the frequent outages in the long-haul signal transmission from the country’s main telecommunication centre to the remote access network. Information

on the area coverage is insufficient, hence, there is a need to reduce downtime on telecoms services to such public sectors and improve coverage;

- Lack of skilled people in Al Qatrūn area exhibits the need to provide training in order for them to take an active part in development programs. Local offices of the GPTC also require the services of skilled personnel;
- There is an unsatisfied need for telephones in Al Qatrūn, thus, urgent action is required to provide better information on demand, increase the capacities and improve the affordability of telecoms services;
- As mentioned above, the location of Al Qatrūn on the main road to Chad and Niger exposes it to an increased level of theft of copper wires, solar cells and vandalism and thus the need to educate the community on the importance of telecommunications infrastructure for their wellbeing in order to improve the security of the infrastructure and reduce the theft and vandalism; and
- From the discussions and interactions with the participants, it became clear from the responses to certain questions asked by the facilitator that the participants did not fully realise the role of telecommunications in the promotion of rural development. Their vision for the future was universal access of telecoms services at affordable rates and that there should be proper planning before infrastructure rollout. The author explained to them how improved telecoms services could help improve economic activities in rural areas.

8.7 Conclusion

Rural telecoms infrastructure selection is a critical task. The GPTC's strategic directives provide guidance on a broader perspective since mid and low-level managers are often faced with making decisions in their own spheres of influence. Hence, empowered managers, who make the decisions, must be aware of the available tools for making such infrastructure technology choices. If they rely simply on their intuitions, important factors could be disregarded.

GPTC was interested in promoting telecoms service deployment in rural and remote areas throughout the country. However, the lack of telecoms backbone infrastructures in such areas was the main obstacle to fulfil this goal. This undertaking, therefore, aimed to enhance and structure the selection process of the most suitable technology among several telecommunication systems to be deployed, as a backbone infrastructure; thus improve rural connectivity in most southern parts of the country. The main contribution of this chapter is to apply the proposed ANP model to a real technology selection problem. It presented a method for rural telecommunications infrastructure selection that allows for the consideration of important interactions among decision clusters and criteria.

The ANP model of the selection process was developed from literature and consultation with experts. It was adapted for GPTC, which acted as a case study for validation of the model and approach. This strategic decision making tool assisted the company in evaluating three technology alternatives. The model suggested Fibre optic cable as a potential backbone infrastructure for Al Qatrun, which is the option that the company is, expected to deploy. The case study helps to verify that ANP is an effective and efficient decision-making tool. The company and decision-makers involved in the case study were generally pleased with the approach as indicated in section 8.5.

An ANP-based model was formulated to select the most suitable telecoms technology for the Al Qatrun rural area. The ranking of the alternatives reached by using the proposed model was expected by the participants. This model provides the structure and the flexibility required for such decisions. It enables decision makers to examine the strengths and weaknesses of the problem, by comparing several technology options, with respect to an appropriate gauge for judgement. Moreover, using the ANP model, the criteria for such a technology selection task were clearly identified and the problem was structured systematically. This model provides the flexibility required for such a resolution. Also, a structured approach is necessary because it can reduce the time and effort in the decision-making process.

Based on the results of this case study, it can be concluded that the application of the ANP in the selection of telecoms technology, is indeed beneficial. Besides, although this study was done for the Al Qatrun rural area, it is believed that telecommunications planners could, by the use of similar data pertaining to another rural area, utilise the developed model to propose appropriate solutions. If new criteria and/or alternatives emerge to satisfy changing business needs, they can also be included in the ANP model; however, this entails increased data collection and perhaps more computational load.

9. CONCLUSION

9.1 Introduction

Telecommunications, in general, is meant to serve society. Thus, the total lack or neglect in providing adequate telecommunications infrastructure to rural communities will hinder the development of those communities and could give rise to societal problems. In rural districts, especially those that are underdeveloped, telecommunications infrastructure plays a more significant role in the primary development of the area and its inhabitants.

A survey and analysis of the prominent and current literature was conducted. The main literature sources included publications in the field of rural telecommunications such as related textbooks that included case studies, research reports, online academic journals along with conference databases, doctoral theses and recognised relevant journals. In addition, a wide systematic scan of publications of the International Telecommunications Union (ITU), which is, inter alia, responsible for setting standards and making recommendations in the telecommunications industry with respect to equipment, general policy, and planning methodologies was carried out. It is a body that has a great contribution to the provision of telecommunications, especially in terms of the research that it has sponsored and the wealth of literature published.

The information and knowledge obtained from all of these sources formed the starting point of this study. The resulted key conclusion led to the conception that the issues surrounding the rural telecommunications infrastructure selection is not only technological but a complex system of other interrelated factors cutting across various aspects of rural areas and their inhabitants. This research was therefore essential because the problems associated with the infrastructure technology selection, especially in the case of rural telecommunications in developing countries, is a multi-faceted, multi-criteria decision making problems. There are several problems characterised by a complex structure of interacting factors that must be considered when dealing with messy rural settings. These factors are hard to quantify requiring consideration of some wide-ranging qualitative factors related to non-technical issues. They will have great impact on the selection process, in respect of the social, environmental, regulatory and demographical concerns.

This final chapter discusses how the goals of the research were achieved. A summary of the research contribution is also given. A reflection on the ANP method adopted in this study is presented. The chapter sums up by giving some concluding remarks and suggestions for possible directions of future research.

The next section shall highlight how the objectives of this study were achieved, thus accomplishing the sixth objective.

9.2 How the objectives of the research were addressed

The objectives of this research are made explicit in section 1.4 of this thesis. The main aim that guided the research was to provide a comprehensive examination regarding rural telecommunications infrastructure selection by conducting an analytical decision analysis within the context of developing countries.

The **first objective** of the research was *to examine and analyse the issues and challenges involved in the selection of rural telecommunications technologies in developing countries*. Two research methods were used in achieving this objective – the traditional literature survey and the interaction with experts from rural telecommunications arena. Following the discussion presented in chapter 2 regarding rural areas in developing countries, one could specify their environment into three general kinds of factors:

- **Economic and demographic factors** refer to the local economy which is based on agriculture or fishing and with a lower income than the urban areas;
- **Geographic factors** refer to the rural populations who are remotely located from major urban centres and also isolated from each other by the nature of terrain; and
- **Physical factors** refer to the under-developed infrastructure, including transport and power networks. Other factors include terrain topography and climatic conditions.

Chapter two of this thesis covered some of the developmental aspects and universal access of rural telecommunications. Yet, the provision of rural telecommunications infrastructure, in developing countries, is regarded as mainly a technology issue, complicated by economic issues. However, the choice of rural telecoms infrastructure calls for investigation of a mixture of non technical factors affecting the selection of telecommunications infrastructure within the context of rural areas in developing countries which was set as a first objective.

To the best knowledge of the author, there were no holistic technology selection approaches available that could analytically address the complex nature of rural telecommunications. Preliminary research on this study indicated that the multicriteria approach would play a key guiding role in the development of the models. This conclusion finally led to the need for a multicriteria approach to the selection of rural telecommunications infrastructure. It was therefore necessary to explore approaches/techniques that were suitable to tackle the complex issues associated with rural telecommunications. This was the **second objective** that is *to explore and analyse suitable MCDM methods, namely, the AHP/ANP that can be applied to select the most appropriate rural telecommunications technologies.* The focus is on the investigation and analysis of suitable methodologies and techniques from the field of multicriteria decision making, which could be used to improve the current selection process of rural telecommunications infrastructure. In order to achieve this objective, it was necessary to review multicriteria methods. One may refer to chapters three and four for further clarification with respect to adopted techniques suitable for rural telecoms infrastructure selection.

The **third objective** was *to formulate generic AHP/ANP decision models for selecting potential technology options concerning rural telecommunications infrastructure.* The techniques described in chapter four contributed through their analytical nature by providing a deeper insight into the issues associated with the selection of rural telecommunication infrastructure. Primarily, a general AHP model was formulated where telecommunication experts from all over the world were invited to make pairwise comparison judgements on the matrices derived from the AHP hierarchy. The collected data were then combined using the geometric mean and the normalised priority weights were determined for the combined matrices using Excel. Finally, at the synthesis phase, the model was established by combining the normalised priority weights in each level of the hierarchy. However, the simplicity of the hierarchical structure and linear unidirectional hierarchical relationships among criteria and subcriteria in the AHP method hide important issues, such as interdependence among qualitative factors and interaction among decision making levels and so oversimplified the problem. Consequently, an ANP model, which incorporates both qualitative and quantitative approaches to a decision problem, was developed. The qualitative part included: identification of the decision problem; ensuring the suitability of ANP to solve the problem; decomposing the unstructured problem to a set of manageable and measurable levels/clusters; and compiling a list of experts to provide judgements for making the decision. The quantitative part included: designing a questionnaire to collect input data through pairwise comparison; estimating the relative importance between any two elements in each matrix and calculating the relevant eigenvectors; measuring the inconsistency of each matrix by employing the consistency ratio; and eventually constructing the supermatrix using the eigenvectors of the individual matrices.

The **fourth objective** was *to develop a comprehensive BOCR-based ANP framework that will enlighten such a selection process in developing countries.* Providing a useful analysis framework and viable solutions to such an important and complex problem is the contribution of this objective. The main goal is to select the alternative, which is the most beneficial and offers the most opportunities while at the same time incurs the least cost and poses the lowest risk. The model was structured by creating three networks: the top-level, the control criteria networks and the decision networks. The comprehensive framework takes into account the interests of the stakeholders. The obtained results indicate that Microwave technology is the most preferred technology alternative within the context of the developing countries. The sensitivity analysis graphs show the robustness of the obtained results. The importance of the topic and the necessity for an all-inclusive analysis framework warrant this effort. This framework enables decision makers of telecommunication companies to structure such a selection problem and reach proper decisions in this regard.

The **fifth objective** was *to validate the generic ANP model in a real case study in Libya, to evaluate its applicability in terms of systematically improving the group decision-making process of the selection proces*s. The case study of the practical implementation of the developed ANP decision model was conducted in Libya, specifically involving its main telecommunications provider, GPTC, in terms of modelling such a selection process for a potential rural area. Apart from its economic development potential, the Al Qatrūn town was chosen because there was a significant rollout of telecommunications infrastructure within the current five-year plan (2005-2010) and the town was on the GPTC list that includes remote rural towns to be connected with the rest of the country. Following the post workshop questionnaire that reflected the participants' satisfaction in the model, they found the ANP method useful and gained a better insight into the choice of rural technologies. They experienced very little difficulties in dealing with identification of dependencies and pairwise comparisons. It was emphasised by the participants who are telecommunication planners that the application itself was successful, especially for their planning purposes and the process represents an improvement on current technology selection practice in rural telecommunications.

9.3 Summary of the research contribution

This research was transdisciplinary in nature. One would expect research such as this to fall within the telecommunications engineering environment. Although the area of concern falls within the telecommunications field, knowledge from other disciplines such as operations research, multicriteria decision making, analytical decision processes, rural development and planning were essential in achieving the objectives of the research. The following paragraphs highlight the contributions made.

This research claims to have made a theoretical and practical contribution to the telecommunications sector. The general nature of the past research in the telecommunications sector, even in developing countries, is skewed towards technological advancement and measuring the socio-economic impact or the ultimate payoff of telecommunications infrastructure. It is characterised by a positivist epistemology, in which the correlation between issues is not the same as cause and effect (Ackoff, 1999).

In this research, emphasis was placed on obtaining a better understanding of the issues involved in rural telecommunications in terms of the interdependencies among these issues. The theoretical contribution of this research includes the formulation of the generic AHP/ANP decision models together with the wider ranging investigation that utilises a BOCR-based (Benefits, Opportunities, Costs and Risks) ANP. They were based on research that include the analysis of the literature and current practices of telecommunications planning and the development of the idea of the conceptual model illustrated in Figure 3.2, and justified on the basis of multicriteria decision making methodology, in particular, the analytic network process.

The proposed analytical decision models enable decision makers to examine the strengths and weaknesses of the problem, by comparing several technology options, with respect to an appropriate gauge for judgement. Moreover, using the ANP, the criteria for such a technology selection task were clearly identified and the problem was structured systematically. This, according to the author, is the first holistic approach with this particular multicriteria combination used for the selection of rural telecommunication infrastructure technology.

Such investigation entailed an analytical analysis to provide the structure and the flexibility required for such decisions for the application area “selection of rural telecommunications infrastructure”. These are new theoretical contributions to the discipline of rural telecommunications as no such applications were reported previously in the literature to the best knowledge of the author. It is envisaged that new knowledge or new insights into rural telecommunications infrastructure selection will be gained as the developed models are applied to different rural situations or probably to other developmental issues as well.

The case study in chapter eight highlighted the practical application of the ANP model within the context of a developing country such as Libya, specifically in the Al Qatrūn town, where great emphasis is placed on community development, and showed the viability of this type of MCDM approach to complex problem solving. The experimental application benefits were evident and demonstrated how the model helped the GPTC telecommunications planners to deal with a complex problem situation, such as the selection of rural telecommunications infrastructure. They were empowered to improve their current practices and felt involved in an inclusive and transparent systematic process in relation to the selection of rural telecommunications infrastructure for a typical rural area (Al Qatrūn), and finally arrive in a methodical way at a suitable technology alternative that could be deployed. This intervention is a practical contribution to the telecommunications sector.

9.4 Reflection on the ANP method used in this research

The aim of this study was to provide a comprehensive examination regarding rural telecommunications infrastructure by conducting an analytical decision analysis that allows for consideration of important interactions among decision levels/clusters and criteria. The methodology derived from the techniques of the analytic network process. A decision support system based on the ANP is presented to assist telecoms planners in the process of decision making for the selection of rural telecommunications infrastructure. The ANP, which has previously been applied in project management research, is deemed a useful decision support technique. Generic AHP/ANP models together with a comprehensive BOCR-based ANP framework developed from literature and consulting experts were presented.

The proposed models are highly tailored for rural telecommunication infrastructure selection in developing countries since they integrate decision elements and relative priorities concerning their specific needs. Similar ANP-based models may also be developed in other contexts as well, which will entail significant time and effort from the decision makers in the formation of the pairwise matrices and some of the criteria adopted in this study may be used for the evaluation of similar rural technological infrastructure (such as rural electrification). However, it is the author's belief that the process of building models of any situation is difficult, and the key to success in this challenge is the recognition of the limitations of any modelling technique used and structure created.

A case study to validate the generic ANP model was carried out in Libya's main telecoms provider. It helps to verify that the ANP is an effective and efficient decision making method. During the case study, GPTC planners voiced their opinions about the strengths and weaknesses of the current rural technology selection process within their company.

The strengths include sufficient time and money to spend on selection process, careful evaluation, expertise from different areas and many criteria considered. On the side of weaknesses, a number of point are mentioned, such as selection criteria not clearly defined, process not systematic, bias towards engineering recommendation, difficult to get consensus and slow decision making. Other weaknesses include lengthy selection period, intervention from senior management, inefficient, no common standard on the selection process and different sections handle the process differently. These weaknesses are the reasons for developing a systematic structure for the selection of rural telecoms infrastructure, prioritise relevant criteria, and balance trade-offs between several different factors like technical, economic, social, environmental, etc.

The ANP allows for consideration of important interactions among decision levels/clusters and criteria, reduces time in such problems and develops consensus decision making. Such a strategic decision making tool assisted the company in structuring such a selection problem and evaluating four backbone infrastructure technologies. As reflected in the post workshop questionnaire, the decision makers involved in the case study were generally satisfied and had a very positive attitude towards the used approach. The author showed that the proposed approach is both practical and robust, via an empirical case study. It is an effective support system modelling tool for high and middle management capable of transforming unstructured decisions into structured ones, by allowing GPTC planners to model the complex rural technology selection problem into a manageable structure that takes into consideration the relationships among attributes and alternatives.

The author believes that the proposed ANP model could be viewed as a vehicle for applying experience, insight and intuition in a logical and thorough manner. More importantly, the superiority and uniqueness of the framework structure as compared to traditional unstructured rural technology selection processes that do not consider interactions among decision elements was demonstrated. This view was also noticed in the workshop process, in such a way that the participants' confidence in the decision making process, and specifically in the final recommendation, increased considerably. They felt that the ANP has provided a precise definition of all the various factors in a manner more easily understood, hence proving to be a very valuable tool at building consensus. Although, at first, the participants felt overwhelmed by the number of pairwise comparisons they had to perform, which is about 542 questions. However, they were relieved by the use of the online questionnaires in which the questions were organised sensibly. Such questionnaires were instrumental and had greatly assisted the author throughout the course of this study to secure all required data and judgments for all developed models.

Due to certain limitations in the current version of the *SuperDecisions*, it was not possible to perform sensitivity analysis on the final results of the case study ANP model. Fortunately, the software developer is currently developing the package, which will include a new feature in relation to sensitivity tests on network models. Once the updated version of the *SuperDecisions* is available, the author will carry out further experimental analysis on the sensitivity of the final results and recommendations can then be made to GPTC planners.

It should be noted that other alternative scientific methods for incomplete judgements such as Harker's algorithm, which was discussed in subsection 4.4.1.2, were not implemented in this study. Based on the author's experience in relation to controlling the number of judgments in the model, one can construct smaller models that include a reduced number of clusters and fewer elements in each. Elements with very small priorities relative to others will have no feedback among them and can be carefully eliminated from the model. Clusters whose limit weight is relatively very small can also be dropped from the model. Judgment effort can be distributed among a group of experts specialised in those aspects of the problem, where the entire group should mainly pay particular focus to the most important aspects.

The application provides important insights and is easily adaptable to various companies when different conditions and specific needs are encountered. For example, priority given to each element in the models is dependent on decision makers evaluating that element. This helps facilitate the tailoring of the models to the concerned company. For instance, a state-owned telecoms company stressing rural development issues would come up with criteria and priorities different from a company seeking to compete as a profit-driven telecoms provider of proven infrastructure technologies.

While the author considers that the models developed throughout this work provide value, there are areas for future enhancements and validation. The developed models are meant to be generically applicable across different companies and rural situations. It is acknowledged that the decision levels involved in any particular implementation would be different depending on the company involved. In fact, the author considers the ability of the AHP/ANP to adapt a basic framework to a particular situation as a strength rather than a weakness. Each application can have defined for it a set of criteria deemed important for that application. A decision criterion and/or alternative that a company considers to be crucial can easily be added to the generic models. Similarly, other stakeholders' clusters can also be added to the BOCR-based ANP framework.

In addition, the generic ANP model, together with the model used in the case study, did not consider all possible dependencies among their structures, because a majority condition of 4 out of 7 (4/7) experts' consensus (i.e. 57%) was set as a minimum requirement for any entry to acknowledge a direct relationship between any pair of elements. Additional interactions between and within decision clusters could have been included if all experts' opinions were considered. The author suggests a more interesting and useful extension of the models by including more interactions and comparing the obtained results, nevertheless then at the cost of complexity.

The limitation of the analysis in the case of Al Qatrun regarding the absence of more recent data was explained in subsection 8.4.2.4; another weakness is the non-inclusion of all related stakeholders in the analysis. These issues render the results given in chapter 8 preliminary, because the selection of technologies in rural situations necessitates that the action and the result has an affect on the stakeholders. Hence, incorporating various stakeholders in the decision making process could enhance the structure and bring out different patterns. The case study model is structured without consideration of the company size limit, which means the model might need significant customization to suit other companies. In other words, the final results may not be directly applicable to other local companies. Moreover, new developments in telecommunications technologies could reveal restrictions on the proposed models. The developed models are capable of evaluating more than four (as in the generic model) to three (as in the case study) distinct technologies regarding rural telecoms infrastructure decisions as has been illustrated. However, there have been proposals for more technology options for companies to consider. In other words, an up to date model for technology selection decisions could include alternatives that are not in the current models.

The adopted ANP method proposed in this study bears also some limitations. These are owed to the approach, which takes into consideration both qualitative and quantitative criteria and incorporates interdependencies and feedback among them. Yet, the outcome of the model depends highly on the inputs provided by the decision makers of the telecoms service providers who must also be knowledgeable and at a strategic level within the company, in order to realise the importance of all aspects. Since, ANP accommodates subjective judgments, the dependency on the decision maker to elicit the weightings, which are based on his /her subjective opinion, is generally viewed as a drawback of the ANP.

However, the author believes that in the real world, successful decision makers exercise judgments that are largely subjective.

Moreover, in this study, provisions were made to overcome such a limitation by implementing a Group Decision Support system (GDSS) involving at least four experts to answer each pairwise question. Consensus of experts is embedded in the preference weightings by aggregating their individual judgments into a combined group judgement. Furthermore, group decision making introduces certain uncertainties about the characteristics of the 'right' answer. Hence, identifying experts' opinions and combining them into a consensus judgment are additional elements of the decision-making process. GDSS is a specialised type of computer-based business information system, which increases participation by group members, reduces group domination by a vocal minority and eventually leads to better decisions.

The formation of the pairwise comparison matrices in the ANP method is a time-consuming and complex task. The process becomes computationally intensive, but this limitation can be alleviated by appropriate software tools to ease the mathematical complexity and in any case, the benefits of risk reduction will outweigh the cost and time. Of particular importance, is the *SuperDecisions* software, which helped the author to efficiently model the problem by clarifying, organising and presenting it in the way decision makers think. It is equipped with a module capable of accommodating apparent inconsistencies that may occur in the decision process, which if left untreated could lead to doubtful or wrong results. The author found the graphical user interface flexible and easy to learn and use. Different types of comparisons, which can be made in either a verbal or a numerical mode, can be selected. Besides, whenever new knowledge becomes available, it can be integrated. For instance, if some important aspects, such as creating connections, adding a criterion and/or alternative were overlooked while formulating the problem, instead of deleting the whole model and starting over, the *SuperDecisions* allows modification of the relevant parts in that model.

From the results of this study, it is the author's belief that despite the abovementioned drawbacks, the ANP provides a systematic and logical approach to structure and analyse decision problems related to rural telecommunications. It is proved to be effective in the case study application to rural telecommunications infrastructure selection. It is highly recommended that GPTC can adopt the formulated ANP model to improve the current rural technology selection process.

The generic ANP model developed in Chapter 6 can readily be used as a basis for rural telecoms infrastructure selection in developing countries. The flexibility of the model allows for the list of criteria and alternatives adopted in the generic ANP model to be refined. In such a case, concerned decision makers could perform measurement and data collection to adjust the dependencies and the priorities of the model. To cater for different business needs or for large scale projects, the author suggests the implementation of the comprehensive BOCR-based ANP framework, which was developed to assist infrastructure providers in their decision making process with regard to rural telecoms infrastructure selection. It takes into account the interests of the concerned stakeholders.

The author anticipates that the major obstacle to the implementation of the ANP is to enlighten telecoms decision makers to understand the principles and methodology of the method so that they can build up confidence in the new approach. Top management endorsement to the ANP is also important to encourage all functional areas to adopt this new planning methodology.

9.5 Concluding remarks and directions for possible further research

This study raises several important issues that could pace the way for further research. Research prospects that can be formulated in several directions include:

- This research was concerned with rural telecommunications infrastructure selection, which traditionally belongs to the discipline of engineering, more specifically electrical/telecoms engineering. Another important technological infrastructure that also traditionally falls within the electrical engineering field concerns the distribution of electricity. Electrifying rural areas in developing countries in general and Libya in particular is currently a high priority with respect to basic services. It is envisaged that many of the issues that rural telecommunications face would be relevant to the distribution of power to rural communities. A possible research direction is to explore the possibility of employing MCDM models, such as the ones developed in this research to structure the problems encountered in the distribution of electricity supply to rural communities.

- It was not within the scope of this research to engage in the deployment, commissioning, and evaluations of the telecommunications infrastructure. Thus, the implementation of the backbone infrastructure technology, which emerged from the application of the model in Al Qatrūn, could be formulated as a research program in terms of further investigating the development that has been triggered.

- One of the factors considered in the models was the access to existing telecommunications infrastructure, which calls for collaboration with other infrastructure providers and other relevant agencies by the rural telecommunications planners. This calls for research into how this could be formalised and how they could be included in the decision making process.
- The rural communities need to be educated and trained with respect to the use, benefits and the importance of taking ownership and protecting the telecommunications infrastructure. Further research on how to conduct such rural community education and involvement into the evaluation of issues affecting them is therefore a challenge.
- Another research proposal is to validate the BOCR framework developed in this study by converting the standard ANP network constructed in the case study into a BOCR-based ANP network. This will allow for testing the framework and refining it with real interactions and involvement of the stakeholders and performing sensitivity analysis on the results to become current practice in the choice of rural telecommunications infrastructure technologies. This framework can also be further explored for selection of other infrastructures that can contribute to rural development.
- A further research avenue is the evaluation of the models and their implementation at additional case studies in related industries. Such an endeavour might be beneficial and result in developing a complete system that could support the decision makers and reveal the significance of certain alternatives, criteria and elements.

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APPENDICES

Appendix A: Criteria and alternatives descriptions

A.1 Criteria description

A Technical: This cluster covers reliability, ease of installation and maintenance, scalability, bandwidth, compatibility, flexibility, remote network management and latency. A description of the elements included in this cluster is given below:

A1 Reliability: refers to consistent speed and service. It is one of several core components that represent the quality of service. Reliability of a transmission system is expressed in different ways by different manufacturers and operators and can use measures such as mean time between failures (expressed in years). Rural telecommunications infrastructure networks must be highly reliable. Their prime requirement of a rural network transmission system is to provide the optimum reliability over the maximum distance at the minimum installed cost. In times of unforeseen service interruptions, inclement weather or disasters, it must provide allowance for quick and easy service restoration. For example, the use of satellite and wireless technologies in rural areas could be affected by weather interference, resulting in poor quality of transmission.

A2 Ease of maintenance: refers to the technology's user-friendliness and adaptability to change. The ability to adjust to varying circumstances defines dimension. It must fit to occurring changes considering the fast phase of technology or cope with the unexpected changes in the environment. This is very important in terms of efficiency and economic success. Similar to installation, concerns on poor maintenance involves poor quality of service in the existing network. Adding new services or extending to new communities will simply compound the problem. However, waiting until the network is fully upgraded may result in delays that keep the country from benefiting from telecommunications services (Hudson 1989). A suitable system should be capable of reconfiguring circuits to maintain services and remotely locate faults at card level so that repairs can be made by semi-skilled labour.

A3 Remote Network Management: is one of the strategies that affect costs and therefore it has to be considered in rural areas. To the extent that systems can be controlled from centralised facilities allowing for economies of scope, the number of physical trips to the installation site is reduced. Thus, the lifetime operation and maintenance costs are minimised. Furthermore, as equipment in rural areas cannot sustain rapid turnover, it is chosen under the constraint that repairing services and spare parts cannot be provided for long periods of time (Gasmi & Virto, 2005) and therefore, it should be equipped with centralised maintenance features capable of reconfiguring circuits to maintain services. Also, to enable maintenance staff to remotely carry out system checks and remotely locate faults at card level so that repairs can be made by semi-skilled personnel.

A4 Compatibility: refers to the capability of the deployed rural telecommunications infrastructure technology to co-exist or operate with other already deployed dissimilar technologies. The long-term focus should be on migrating to a more efficient telecommunications infrastructure based on digital and radio technology that comply with technology standards and use of open standards. The open standards option means that adjacent and overlapping networks are compatible with each other. As a result, network development is readily scalable and has expansion paths that can be adjusted to suit future needs and increased network density, stressing network compatibility along the way. Otherwise, interconnection of communication networks will be inefficient or even impossible, and potential synergies are lost.

A5 Ease of installation: Considering the relative degree of difficulty for the construction of backbone telecommunications infrastructure, significant challenges are expected and therefore, ease of installation, depending on transmission medium chosen and applicability to rural area where it will be built and housed, must be one technology selection factor. Easy installation of backbone networks combined with minimum field alignments, are necessary at localities, characterised by being remote and rural. They must also be easy to transport and install in deserts, forests, mountains, isolated areas, etc.

A6 Scalability: To what extent are the solutions offered by the rural telecommunications infrastructure technology scalable i.e. possible for general applications as opposed to only local solutions, in that they can be expanded incrementally? An example is provided by scalable radio networks that allow capacity to be modified from a few hundred to a few thousands users without substantially affecting hardware and software configurations.

A7 Bandwidth: In electronic communication, bandwidth refers to the range (or band) of frequencies that an electronic signal uses on a given transmission medium. In this usage, bandwidth is expressed in terms of the difference between the highest-frequency signal component and the lowest-frequency signal component. In analogue systems, the frequency of a signal is measured in terms of Hertz (Hz) (i.e. the number of cycles of change per second), a given bandwidth is thus the difference in hertz between the highest frequency the signal uses and the lowest frequency it uses. In digital systems, it is measured in bits per second (bps) and so the higher the bandwidth, the greater the amount of information that can be transmitted in a given time. High bandwidth channels are referred to as broadband, which typically means higher speed at which one can upload and download information (ITU, 1997).

This is relevant for both voice and data communication. Typically, voice (including Voice over Internet Protocol [VoIP]) communication requires 8 Kbps to 64 Kbps (symmetrical), depending on the type of CODEC used. An analogue television (TV) broadcast video signal has a bandwidth of six megahertz (6 MHz) (i.e. some 2,000 times as wide as the voice signal). Data communication can generally use any speed; however, it is usually only for data connectivity that a given speed would be quoted by a service provider and is thus a parameter to which an individual might subscribe. Evidently, each technology has a finite upper limit to what data rate it can provide. The data transfer capacity of the infrastructure technology, including both upstream and downstream bandwidths enhances the potential for new services. Therefore, the question to be asked when selecting telecoms technologies is to what extent will the new technology increase the transport speed and delivery of data?

A8 Flexibility: refers to the ease of expansion of the rural telecommunications infrastructure technology. Technical flexibility is deemed important because rural infrastructure technologies must be flexible in terms of the service they can provide, including data and voice (Hudson, 1988). It is intended to force consideration about the constraints each alternative could impose on the way that the business could develop. For example, would certain applications be technically infeasible were one of the technology options adopted?

A9 Latency: refers to the time between the moment a voice packet is transmitted and the moment it reaches its destination, i.e. the amount of time required for data to traverse a system and get from point A to point B. Obviously, low latency is best. Voice services are particularly susceptible to severe degradation with high latency. For example, one drawback of several satellite-based technologies is a higher latency time and a significant delay due to the long distance travelled by data. Latency is particularly significant in the context of VoIP and packet-based technologies wherein interaction time is important. It is caused by slow network links and called lag, which of course leads to delay and finally results in echo.

Latency is measured in milliseconds (ms) - thousandths of seconds. A latency of 150ms is barely noticeable so is acceptable. Higher than that, quality starts to suffer. When it gets higher than 300 ms, it becomes unacceptable. The effects of latency over voice quality include:

- It causes echo and slows down voice conversations;
- Untimeliness results in overlapping noises and speakers interrupting each other;
- Disturbs synchronization between voice and other data types, especially during video conferencing.

It should be noted that references to latency in this research are focused only on latency in the network and not latency end to end incorporating whatever applications or servers are implementing the services at the client and server. These themselves can be quite significant and need to be addressed in an overall solution design.

B Infrastructure: This cluster includes infrastructure related issues, which contribute to the evaluation of backbone infrastructure technologies. The criteria are arranged in it as given below:

B1 Coverage range: refers to how well the proposed system is able to cover wider areas. The required coverage range capability could be: territory coverage, a household service penetration, clusters, dispersed, uniform or sporadic. It is mostly relevant to wireless access technologies and is usually expressed by an operator in the form of percentage of population in a given area able to access the service or percentage of the geographic area in a given country where the service is available. In wireline network terminology, the key measure for coverage would be the number of points of presence, in terms of either absolute customer connections or absolute inter-carrier connections.

B2 Security of physical infrastructure: Protecting rural telecommunications networks from vandalism or theft is critical to the smooth operation of any application. For example, the deployment of telecommunications technologies requires a local power supply. However, the theft of installed solar panels required to power the telecommunications equipment, and the theft of copper cables in outlying rural areas are posing a major challenge in most developing countries. Such problems can increase network exposure to vandalism, thus raise material and labour costs as well as lost network time.

B3 Proposed usage: refers to the current and future usage diversity of the projected infrastructure technology. The emphasis nowadays in considering telecommunications in rural areas is mainly on applications, addressing how the telecommunication services will be used, and how, in turn, this usage will benefit the communities of the region served?

B4 Availability of skilled technicians: Skilled manpower is rarely found in rural areas and the requisite skills may not even exist in the immediate locality. For instance, PC hardware configuration has been considered as the most difficult task faced when deploying rural projects in developing countries due to the absence of local expertise (ITU, 2004). Such lack of technical support and equipment repair facilities in rural areas increases the cost of operation and maintenance of rural systems. Therefore, equipment installation and repair become time consuming and expensive. For instance, when telecommunications equipments develop fault, it is difficult to send experts to repair it, because of the remote locations of the equipment sites and thus the fault restoration time is lengthier than in urban areas.

As a result, in order to reduce the economic impact of inadequate maintenance and low computer literacy in rural areas, developing countries have been favouring simplified access device configuration and operation and therefore, deployment of infrastructure technologies must be accompanied by effective human resource development and training.

B5 Access to existing telecommunications infrastructure: refers to the sharing of the telecommunications network infrastructure whenever it is cost effective to do so by making use of the existing public infrastructure assets such as radio towers, electricity clamps, public buildings, etc, and guiding the replacement of older network facilities with advanced ones. This is in order to facilitate and minimize the investment required to build the backhaul and last mile infrastructures to cover the remote and dispersed rural environment. The expenditures of providing separate infrastructures could be prohibitive in the short to medium term. In order to reduce costs and to utilize the scarce resources to their maximum capacity, the best approach is to leverage what is available and to share resources wherever possible.

The economic necessity of utilising existing telecommunications infrastructures can be elaborated as follows:

- The problem of interfacing new systems to existing equipment;
- Existing systems are often not easily expanded; and
- The maintenance costs on existing equipment are higher.

B6 Remoteness of area: Besides the population’s low density in rural areas, distance to the Local Exchange (LE) / Public Switched Telephone Network (PSTN) - this is the same thing as POTS (Plain Old Telephone System) or simply the worldwide telephone network - is another factor. There is a concern in which telecommunication services have tended to be provided in those areas that are near to the existing telecommunications infrastructure such as PSTN. The result of this is that telephone density as an example has increased substantially in some parts of the country while others lag far behind.

B7 Rollout time: refers to the time required to deploy the planned telecommunications infrastructure technology in rural areas.

B8 Parallel infrastructure: refers to readily basic infrastructure needed to support advanced telecommunication services in rural areas. Power supply, for example, is required for the operations of telecommunications equipments. However, in cases where it is available, it tends to be unstable and unreliable which causes another real predicament. This poses a difficulty in running telecommunications equipments on batteries for long hours. There is also the problem of insufficient voltage or over voltage, and to stabilise power at an even level is difficult and costly. Therefore, telecommunication technologies with low power consumption are highly recommended in rural areas because the incentives for an operator to use telecommunications access devices with minimal power requirements and compatibility with renewable energy resources such as solar energy are extremely high (Gasmi and Virto, 2005).

Readily available roads and transport will have a significant impact on the issue of maximising the benefits of telecommunications infrastructure technologies for rural development. However, the unavailability of accessible roads compounded with poor levels of rural transport infrastructure networks, which are often small and not well maintained in rural areas hinders both mobility and accessibility. This will subsequently increase the cost of establishing, operating and maintaining telecommunication networks in rural areas. For example, telecommunications cables are generally laid by the side of the roads; laying down these lines becomes expensive and difficult because of non-availability of appropriate roads.

C Economic: Despite the price reductions made possible by new technologies, the cost of installing rural telecommunication networks will remain substantially higher than that of installing urban networks and as is normal, the cost of telecommunications infrastructure in relation to projected revenue streams will influence investment decisions. The challenge remains, how to make rural areas as attractive to network providers as more densely populated areas? The author believes that such costs can be reduced by proper planning, engineering and design of rural networks so that the principle of cost effectiveness and logical technological solutions can be adopted. A brief account of the criteria that are included in this cluster is given below.

C1 Operating cost: refers to *Operating Expenditures* that comprises costs of maintenance and administration, training, testing, spares, theft and vandalism, depreciation and upgrade. It depends on the number of rural users. Capital costs are important, but also costs of operation and maintenance are vital contributors. Different infrastructure technologies offer different features and not all these features are capable of quantification in monetary terms, hence value judgements are necessary.

C2 Funding sources: refers to the process of getting access to the necessary funds to enter the rural areas that are suffering from market failure. This is of paramount importance, because the shortage of funds for rural telecommunications is a worldwide problem. This matter becomes a key issue for the success of the provision of rural telecommunication services. Initial prices are important, but an important consideration is the high cost of establishing a telecoms network in rural areas.

C3 Capital cost: refers to *Capital Expenditures* required for deploying rural telecommunications access technology. They include: purchase, deployment and recovery costs. Purchase costs include the expenditures incurred on the cost of telecommunications equipment, its accommodation and land purchases to be used in the deployment of telecommunication services. Capital costs are fixed and are independent of the level of output. They are one-time expenses, although payment may be spread out over years.

C4 Return on investment (ROI): refers to the expected return on capital investments. The return on investment is also directly related to the degree of risk and policy or regulatory frameworks. As a result, the suppliers of the financial resources that are required for the deployment of telecommunication infrastructures and services are interested in the return on capital investments.

C5 Economic development of area: Experience indicates that the introduction of sufficient quantities of modern tele-communication services in previously unserved or underserved rural and remote areas stimulates economic development (ITU, 2000). Some rural areas in developing countries are being economically developed, self sufficient, and people living there can afford high cost alternatives for a better experience. In such areas, telecommunication infrastructure providers can deploy a common backbone for all access types, reducing operating and capital costs while allowing economies of scale.

D Social: The elements in this cluster are:

D1 Demand: An important question for the development of rural telecommunication services is whether the demand for communication services is sufficient to make the proposed services economically viable. The demand for telecommunications in the rural areas of developing countries is low; such demand arises in small pockets which are generally widely separated and, therefore, expensive to satisfy. However, although the demand is low, rural networks should meet the present and expected future demands because the various agencies and institutions required for rural development need telecommunications for the conduct of their everyday business (Chasie, 1976). Also, as development increases in a particular rural area, the demand for services will grow; therefore, technology has to cater for a rapid increase in capacity so demand accelerates.

D2 Affordability: In rural areas, the affordability of telecommunication services to local people can be a barrier towards further development. Although there is an obvious need for access to telecommunication facilities in rural areas, it may not be possible to provide the service at prices affordable to the local community (Falch and Anyimadu, 2003). Public access at a nominal cost must be provided using a public pay phone and/or community access point. This will make available an affordable alternative to ownership of communications equipment such as telephones, computers and internet connectivity. This could also minimize the high cost of providing services to the rural areas.

D3 Population density: This factor therefore has to be considered as an essential criterion when selecting rural technologies because as was previously stated, rural areas are mostly characterised by having relatively low population density and dispersed settlement pattern. This low population density results in lack of infrastructure, higher cost of building and maintaining infrastructure, and lack of market incentives for investment in infrastructure. Rural inhabitants, especially in developing countries, are frequently relocating, where the settlement pattern could be dispersed, clustered, underdeveloped, scattered etc. It is obvious that it does not make economic sense to spend large sums of money on infrastructure to serve a very small portion of population.

D4 Community of interest: A community of interest can be defined as collaborative group of users that share common cultural, linguistic, or economic ties. They must exchange information in pursuit of their shared goals, interests, missions, or business processes and therefore must have shared vocabulary for the information they exchange. Obviously, rural communities have substantial interests well beyond their immediate geographical and administrative vicinity. Therefore, their communication needs have to be taken into consideration when planning rural telecommunications networks so that traffic can be easily routed between villages, even if they happen to be in different regions.

Nowadays, while there may be capacity surplus in transcontinental optical Fibre capacity, there can be shortages in capacity linking communities of interest (Hudson, 2006). For example, a computer user in Cairo who wants to listen to a sermon via streaming audio from a web site in Qatar must use a connection that runs from Cairo to Amsterdam to

Atlanta then back across the Atlantic into the Persian Gulf. The result is a painfully slow Internet connection (Romero, 2001 adapted from Hudson, 2006).

E Regulatory: This cluster contains the following elements:

E1 Spectrum availability: refers to the spectrum or range of radio waves available used as a transmission medium for cellular radio, radio paging, satellite communication, microwave links, over-the-air broadcasting and other services. The radio spectrum is split into different bands, which are used, by a wide variety of services like emergency, mobile phones, commercial radio and television, terrestrial microwaves, and satellites. Within the radio spectrum, there are some bands, which are open for public use, and some, which are only available to the highest bidder. At the international level, this is done by the International Frequency Registration Board (IFRB) of the ITU. Individual national regulatory agencies monitor the occupancy of the radio spectrum and allocate frequencies to individual users or a group of users to enable a large number of services to operate within specified limits of interference.

With regard to wireless media, the growth in demand of mobile technologies has increased the demand for bands of spectrum. Availability of suitable radio spectrum dictates the quality of service, which can be provided to customers. To a certain extent, some solutions avoid regulatory hurdles by using radio spectrum in bands that do not require licensing in many parts of the world. The unlicensed 2.4GHz and 5GHz spectrums have been used by communities in many countries to build their own wireless networks to provide their basic voice and data services without billing users. However, once a network is running, telecoms services have to be reliable, but it is harder to offer a robust consistent service using unlicensed spectrum, which can deter business users, who provide most revenue.

Licensed spectrum is auctioned off to the highest bidder in many countries and there is a high price to pay for some frequencies. In addition, there are considerable national variations on this and virtually all countries require special permission for the higher power radios that would be most useful in rural areas. For example, for radio systems, there is a requirement that any 1800MHz and 3G radio spectrum licenses issued are required to pay the frequency spectrum use fees. It is generally regarded as reasonable as long as pricing is cost-based. However, in some countries there is a concern about the high license fee for frequency spectrum.

E2 Licensing constraints: In some developing countries, the service delivery concern was to some extent due to the license restrictions on telecommunication companies. For instance, in some cases only fixed telecommunications technology could be utilized to deploy voice services to rural communities. This has hindered the potential use of other newer and cost-effective wireless technologies and has resulted in potentially more costly solutions. It can be much easier if one can remove the work of obtaining a license.

E3 Rights of way: Rights of way are required to rollout rural telecommunications backbone infrastructure. Therefore, it is required to provide space along the national road / train networks for installation of the required infrastructure to link the villages. The body, which is responsible for the apportionment of the rights of way along the road / train networks in the villages, is required to provide space for installation of the required infrastructure to connect individual customers.

F Environmental: This cluster contains the environmental influences of rural areas where the network infrastructure technology will be built and housed. These factors include terrain topography and climatic conditions.

F1 Terrain topography: One of the key distinguishing features of rural areas is the topography of the land. Difficult topographical conditions, e.g. lakes, rivers, hills, mountains or deserts, render the construction of wire telecommunication networks very costly. For instance, in hilly areas, which are mostly rural, microwave Ultra High Frequency (UHF) becomes impossible, because hills come between two sites.

F2 Climatic conditions: Telecommunication networks should withstand different harsh climatic conditions frequently encountered in rural areas. For example, in some rural areas, there may be snowfalls causing short-circuiting and power failure. In addition, in extreme weather conditions especially in warm hilly areas, Alternating Current (AC), which is necessary for the proper functioning of telecommunication equipments, may not work.

A.2 Alternatives description

G Alternatives: This cluster holds transmission alternatives of rural telecommunications infrastructure technologies. For this study, four traditional technology options that allow for establishing a connection from urban centres to remote and rural areas are considered and these are:

G1 Fibre Optic Cable: Fibre optics is a length of glass through which wavelengths of light that use higher frequencies are transmitted to convey digital signals. These signals provide a high capacity alternative to copper or microwave. Compared to copper wires, it is relatively new technology, but can be expensive to deploy, because it needs to be placed underground or underwater. Also depending on distance, repeaters and amplifiers are needed to be installed and subsequently maintained. Once in place, it offers significantly higher bandwidth, greater capacity, high system availability and hence higher transmission speeds (CGAP, 2008).

Fibre-based technology is primarily used to connect network elements and interconnect networks (wired and wireless, national and international). Due to its lower transmission loss requiring no intermediate repeater, in some large developing countries, it is used for extension from an urban gateway to the rural hub centres. Since the costly elements of Fibre cables are the actual laying work of the cable and the termination equipment, it is typically installed in large bundled strands to accommodate future bandwidth needs. While considerable technological advances were made in Fibre transmission in the 1980s, it was not until the late 1990s, coinciding with the formal standardization of the Fibre access-technology by the ITU-T, when the most significant gains were made in performance and cost reduction.

This improvement has established standards, which is usually a pre-requisite for mass adoption of a technology. It then permits interoperability among vendors' equipment and creates an environment that encourages companies to compete in equipment price and performance, and to develop a wider range of product features. Impressive technological advances in Fibre splicing, trenching, Fibre ducts, connectors and enclosures have reduced installation costs significantly. These new technologies and processes make Fibre installation easier, less time consuming, reduce labour costs, and thereby have made the technology more feasible to deploy. The cost of Fibre rollout is currently approaching near to the cost of other wired networks.

Fibre Optic cables can be extended along existing transportation infrastructures, i.e. railway and highway networks to remote distribution networks. Major costs associated with this option include cost of optical Fibre cables and costs of labour and installation. Furthermore, while most Fibre optic cables are laid in the ground, some companies nowadays have started using aerial cables to connect homes. This decreases the cost of installation and makes use of existing power poles as anchors.

The importance of the availability of a public power grid is not just for the supply of electrical power for the telecommunications equipment. The use of a dielectric transmission medium, such as a Fibre optic cable, which is not susceptible to electromagnetic interference for telecommunication signals, provides an opportunity for collaboration between power distribution utilities and the telecommunication network operator. The cables for the network could piggyback on the power grid rights of way, thus reducing the capital expenditure and utilising less natural and human resources.

G2 Power Line Communication (PLC): PLC is a simple concept, which means data transfer via a combination of the power network within the home or office and the metropolitan power distribution grid. It is emerging as a further telecommunications platform that uses available power lines for telecommunication instead of having to install dedicated cabling (CGAP, 2008). If deployed on a large scale it could provide competition to incumbents in both access and backbone parts of the network. Sending data via this communication medium can save costs, because it implements standard electrical power lines, which form one of the most extensive networks in the world, surpassing the phone network in size and coverage.

PLC uses transmission above 1MHz over a power cable combining signals and electricity. The wide-ranging deployment of the electric power system enables PLC to reach outlaying rural areas and provide data speed of transmission comparable to Asymmetric Digital Subscriber Line (ADSL) into the customer's end. It allows simultaneous transmission of voice and data, which means that one can make telephone calls while using the internet. Some of the disadvantages of this technology are data signal disruption due to noise, potential to interfere with radio transmissions and attenuation over long distances, television, telephone, and DSL signals, etc. As power lines are typically untwisted and unshielded, they are essentially large antennas, and will broadcast large amounts of radio energy.

G3 Microwave Links: Microwave links technologies that employ Earth-based transmitters and receivers are available and have economical advantages to provide access to rural and remote areas. They can offer the long-range transmission from urban centres to rural hub stations. Where a microwave link is feasible to connect remote rural areas to the urban centres, it will offer a true alternative to leased lines. Major costs associated with this option include cost of the microwave station and spectrum fee. Bandwidth and signal reliability offered by a microwave link are much lower than that offered by optical Fibre.

By far the most common question asked about wireless propagation is 'how far can a link go?' However, the range depends on the expected availability and data rates required, as well as governing factors of the environment such as the height of the equipment used and how clear the line of sight is. Modern planning tools can correlate the technical performance of the systems with the topographical terrain data of the rural locations in order to reliably predict the bandwidth of the link as well as calculate the desired availability. The technology can therefore establish reliable links even in non line of sight conditions, delivering very fast speeds with high levels of reliability, even in very low-lying urban deployments.

The strength of the return on investment for microwave systems lies in the speed and simplicity of their deployment compared to the alternatives. Historically, microwave links were only deployed on very tall masts or towers that were usually owned by a third party and attracted expensive annual site fees. However, as modern systems can now be easily mounted on a rooftop, equipment can be simply deployed on the user's own building, similar to a residential satellite dish. This enables a system to be installed very quickly with little or no recurring costs (depending on the equipment/labour support contract required). A microwave link can deliver over ten times the capacity of a normal 2Mbps leased line. However, the fully installed cost can be as low as a fraction of the cost of a leased line installation. Furthermore as a capital expenditure the system is owned by that organisation, is not subject to third party service rates and does not attract the expensive recurring costs of a leased line.

Microwave systems operate in the low-gigahertz (GHz) range, typically at 4-6 GHz and 21-23 GHz and use licensed bands at various frequencies. This limits all communication to line-of-sight and costs are highly variable depending on requirements. A microwave link frequency is used to transmit signals in instances in which it would be impractical to run cables. For example, if there is a need to connect two networks separated by a public road, the local regulations usually restricts the running of cables above or below the road. In such a case, a microwave link is an ideal solution. However, a license must be obtained following a licence application to the regulator. The equipment must also be installed and maintained by licensed technicians. The process is specific to the intended rural location and the desired performance of the link, which can be time consuming.

The professional systems that operate nowadays can offer speeds up to 200Mbit/s, however, new higher frequency microwave bands are soon to be released in countries like the UK. Some very high frequency bands, such as the 80GHz band, already widely used in the USA, will allow faster systems to offer speeds of over 2Gbit/s. Microwave links offering truly "fibre" speeds will become an alternative to fibre lines in the very near future, just as they are alternatives to leased lines today.

G4 Satellite Communications: While satellite connections are more expensive than other methods of delivery, they provide a viable option to rural and remote areas that have no other telecommunications alternatives. The advantages of satellite-based services are well known for remote or hard to reach areas and in situations requiring high reliability or multi-casting communications. Satellite systems are also likely to be more reliable, more robust and easier to maintain than wired and terrestrial wireless systems. This is important for deployment in rural areas with no parallel infrastructures, especially in mountainous, jungle or desert terrains. In most rural backhaul situations, distances are large, terrains are difficult, and bandwidth is small. In such cases, satellite becomes the most straightforward solution. However, even with satellite there are many options. One is the Very Small Aperture Terminal (VSAT) technology, which in particular, offers simplicity and economy in network design.

A satellite dish can be a viable option to communicate with remote stations. In addition to the cost of the equipment, this option involves leasing of bandwidth on a commercial satellite. One of VSATs major disadvantages is its limited bandwidth (up to 2 Mbps). In some cases, the satellite system is used as the main downlink and then the last mile network is used to deliver services to end users. Satellites allow isolated areas to have almost the same level of service as densely populated urban areas. One of the main advantages of a satellite-based network is that it can be installed at very short notice to individual homes located in remote areas or areas where the typology doesn't allow terrestrial access.

Satellite technology usually comes to the fore as a broadband medium where no terrestrial technologies can be rolled out. It can be a solution when used in combination with fixed wireless access to bring broadband to small communities. Satellite broadband should be ideal for rural communities but to date it remains a very peripheral broadband solution. Central to this is the problem of latency regarding two-way communications. Latency is caused by the distance data has to travel. Satellite communication has a high latency problem caused by the signal having to travel 22,000 miles (35,000 km) out into space to the satellite and back to Earth again. The signal delay can be as much as 500 ms to 700 ms. This is far worse latency than even most dialup modem users can experience, at typically only 150-200 ms total latency. Beyond latency, satellite systems can be a very expensive solution. The underlying cost of the hardware and the installation means that system set up charges may typically be high. Once installed the monthly costs abate and near the terrestrial offers. This means that other rural regions in developing countries with low density and less developed infrastructure may still benefit from using satellite technology.

Appendix B: Online survey's questionnaire

This survey is intended to identify relevant criteria for the selection of the most appropriate rural telecommunications "backbone" infrastructure to deploy e-services applications in rural areas of developing countries. In order to assess the degree of importance of each selection factor given below, please complete the assessment of their importance using the 5-points scale shown below. If you are not familiar with any of the factors, kindly skip that scale without marking.

1	Not important	2	Moderately important
3	Strongly important	4	Very strongly important
5	Extremely important		

	1	2	3	4	5
Funding Sources					
Capital cost					
Operating cost					
Return on investment					
Economic development of area					
Bandwidth					
Latency					
Reliability					
Flexibility					
Scalability					
Compatibility					
Ease of installation					
Ease of maintenance					
Remote network management					
Availability of skilled technicians					
Rollout time					
Parallel infrastructure					
Terrain topography					
Climatic conditions					
Remoteness of area					
Coverage range					
Proposed usage					
Existing Telecoms Infrastructure					
Population density					
Demand					
Community of interest					
Affordability					
Spectrum availability					
Rights of way					
Licensing constraints					
Security of physical infrastructure					

Finish Survey

Figure B.1 A screenshot of the online survey questionnaire

Appendix C: Online survey results

Table C.1 Online survey ratings results

Respondents	Factors																													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	5	5	5	2	3	5	3	4	3	3	5	2	5	5	1	3	3	4	2	5	5	4	5	5	3	2	3	5	3	5	3
2	4	4	3	3	4	2	2	2	2	3	3	3	3	4	4	4	3	5	5	5	5	5	4	5	5	4	4	5	5	5	4
3	5	4	4	4	3	5	3	3	3	4	4	3	4	4	3	4	3	4	3	4	4	4	3	3	4	3	4	5	4	4	3
4	5	4	3	1	1	2	2	4	2	2	3	4	4	5	3	2	2	2	2	4	5	3	3	2	4	4	4	5	2	5	4
5	1	4	4	2	3	3	3	5	4	5	4	2	3	4	1	3	2	5	5	5	5	5	3	4	4		3	4	2	2	2
6	5	4	4	5	4	5	5	5	4	4	5	4	4	5	4	4	3	3	3	3	4	4	3	3	4	3	3	3	4	3	5
7	3	4	4	3	3	4	4	4	3	3	4	4	4	3	2	3	2	3	3	3	4	4	4	4	4	4	3	3	3	3	4
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9		4	4	5	2	2	5	4	3	4	2	4	4	4	2	4	4	4	3	3	4	5	3	3	3	3	4	4	4	4	3
10	4	4	5	4	4	4	4	4	4	4	4	4	4	4	3	3	2	2	2	1	4	3	2	3	4	3	4	4	4	4	4
11	3	4	4	4	3	3	2	3	3	3	4	3	2	3	3	3	2	5	3	2	3	3	2	3	3	3	4	4	4	4	3
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13	1	5	5	4	4	3	3	3	3	3	3	4	4	4	4	3	2	2	2	2	2	3	3	2	4	5	3	3	3	5	4
14	2	2	4	2	1	5	5	5	5	5	5	3	3	5	2	3	1	5	2	5	4	4	5	5	4	1	3	4	1	3	5
15	5	3	4	3	2	1		4	5		4	5	5	4	5	2	3	2	2	4	5	4	2	4	5	4	5			2	2
16	5	5	5	5	5	4	4	4	4	4	5	4	4	4	4	4	4	5	4	4	4	4	4	4	4	4	5	5	5	5	5
17	5	4	4	5			5	5	5	3	2	3	3	2	3	1	2	3	2	2	1	1	1	3	3	1	3	3	2	2	3
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39	4	3	4	3	4	5		5	4	4	4	4	4	3	3		4		4	4	4	3	5	4	3	3	3			3	3
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53	5	4	5	4	4	5	4	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
54	5	4	4	5	5	5	5	5	5	5	5	5	4	5	4	4	4	4	5	4	4	4	5	5	5	5	5	5	4	4	5
55	5	5	5	5	3	5	4	5	5	5	5	4	5	3	3	4	5	4	4	3		4	4	3	4	3	3	3	3	4	5
56	5	4	4	4	3	3	3	4	4	4	3	3	4	3	4	3	3	3	3	4	3	3	3	3	4	4	4	3	3	4	4
57	5	5	5	3	4	5	5	5	5	5	5	5	5	5	5	3	5	5	5	5	5	5	5	5	5	5	5	5	4	3	5
58	4	5	5	4	4	4	5	4	5	5	5	5	5	5	4	4	3	5	4	4	5	4	4	4	4	4	5	5	5	5	4
59	4	5	3	5	4	3	2	4	3	4	4	5	4	3	4	3	2	5	4	3	4	3	4	4	5	5	4	3	3	3	4
60	5	5	5	5	1	4	1	3	4	4	4	2	4	4	1	3	4	4	4	4	4	5	5	4	4	3	5	5	5	5	5
61	3	3	4	4	3	4	3	4	5	5	4	3	4	3	3	3	3	2	2	3	3	2	2	2	3	2	4	4	2	4	4
62	5	3	2	2	2	3	1	2	3	2	3	4	4	3	4	2	2	1	3	2	2	4	4	4	4	2	5	3	3	2	2

Table C.2 Online survey results in percentage

	1	2	3	4	5	Responses	Average Score
Funding Sources	2 (3.28%)	5 (8.20%)	10 (16.39%)	10 (16.39%)	**34 (55.74%)**	61	4.13 / 5 (82.60%)
Capital cost	0 (0.00%)	4 (6.45%)	13 (20.97%)	**25 (40.32%)**	20 (32.26%)	62	3.98 / 5 (79.60%)
Operating cost	0 (0.00%)	4 (6.45%)	10 (16.13%)	23 (37.10%)	**25 (40.32%)**	62	4.11 / 5 (82.20%)
Return on investment	1 (1.61%)	11 (17.74%)	17 (27.42%)	14 (22.58%)	**19 (30.65%)**	62	3.63 / 5 (72.60%)
Economic development of area	6 (10.00%)	7 (11.67%)	18 (30.00%)	**20 (33.33%)**	9 (15.00%)	60	3.32 / 5 (66.40%)
Bandwidth	1 (1.67%)	9 (15.00%)	**20 (33.33%)**	17 (28.33%)	13 (21.67%)	60	3.53 / 5 (70.60%)
Latency	4 (7.14%)	7 (12.50%)	**22 (39.29%)**	14 (25.00%)	9 (16.07%)	56	3.30 / 5 (66.00%)
Reliability	0 (0.00%)	5 (8.06%)	11 (17.74%)	**25 (40.32%)**	21 (33.87%)	62	4.00 / 5 (80.00%)
Flexibility	0 (0.00%)	10 (16.13%)	**21 (33.87%)**	20 (32.26%)	11 (17.74%)	62	3.52 / 5 (70.40%)
Scalability	2 (3.39%)	7 (11.86%)	19 (32.20%)	**21 (35.59%)**	10 (16.95%)	59	3.51 / 5 (70.20%)
Compatibility	0 (0.00%)	7 (11.29%)	14 (22.58%)	**25 (40.32%)**	16 (25.81%)	62	3.81 / 5 (76.20%)
Ease of installation	3 (5.00%)	7 (11.67%)	10 (16.67%)	**24 (40.00%)**	16 (26.67%)	60	3.72 / 5 (74.40%)
Ease of maintenance	1 (1.61%)	6 (9.68%)	9 (14.52%)	**26 (41.94%)**	20 (32.26%)	62	3.94 / 5 (78.80%)
Remote network management	1 (1.67%)	2 (3.33%)	17 (28.33%)	**23 (38.33%)**	17 (28.33%)	60	3.88 / 5 (77.60%)
Availability of skilled technicians	5 (8.06%)	8 (12.90%)	**20 (32.26%)**	19 (30.65%)	10 (16.13%)	62	3.34 / 5 (66.80%)
Rollout time	2 (3.51%)	11 (19.30%)	**25 (43.86%)**	17 (29.82%)	2 (3.51%)	57	3.11 / 5 (62.20%)
Parallel infrastructure	3 (4.84%)	17 (27.42%)	**25 (40.32%)**	13 (20.97%)	4 (6.45%)	62	2.97 / 5 (59.40%)
Terrain topography	4 (6.78%)	12 (20.34%)	**20 (33.90%)**	12 (20.34%)	11 (18.64%)	59	3.24 / 5 (64.80%)
Climatic conditions	4 (6.45%)	**19 (30.65%)**	**19 (30.65%)**	13 (20.97%)	7 (11.29%)	62	3.00 / 5 (60.00%)
Remoteness of area	5 (8.06%)	13 (20.97%)	15 (24.19%)	**19 (30.65%)**	10 (16.13%)	62	3.26 / 5 (65.20%)
Coverage range	1 (1.64%)	6 (9.84%)	11 (18.03%)	**29 (47.54%)**	14 (22.95%)	61	3.80 / 5 (76.00%)
Proposed usage	4 (6.67%)	8 (13.33%)	18 (30.00%)	**20 (33.33%)**	10 (16.67%)	60	3.40 / 5 (68.00%)
Existing Telecoms Infrastructure	4 (6.67%)	11 (18.33%)	**18 (30.00%)**	16 (26.67%)	11 (18.33%)	60	3.32 / 5 (66.40%)
Population density	4 (6.56%)	8 (13.11%)	16 (26.23%)	**21 (34.43%)**	12 (19.67%)	61	3.48 / 5 (69.60%)
Demand	3 (4.92%)	4 (6.56%)	12 (19.67%)	**27 (44.26%)**	15 (24.59%)	61	3.77 / 5 (75.40%)
Community of interest	3 (5.00%)	8 (13.33%)	**21 (35.00%)**	17 (28.33%)	11 (18.33%)	60	3.42 / 5 (68.40%)
Affordability	0 (0.00%)	7 (11.29%)	**21 (33.87%)**	16 (25.81%)	18 (29.03%)	62	3.73 / 5 (74.60%)
Spectrum availability	2 (3.45%)	2 (3.45%)	**23 (39.66%)**	13 (22.41%)	18 (31.03%)	58	3.74 / 5 (74.80%)
Rights of way	3 (5.26%)	12 (21.05%)	16 (28.07%)	**17 (29.82%)**	9 (15.79%)	57	3.30 / 5 (66.00%)
Licensing constraints	2 (3.28%)	9 (14.75%)	**19 (31.15%)**	17 (27.87%)	14 (22.95%)	61	3.52 / 5 (70.40%)
Security of physical infrastructure	3 (4.84%)	5 (8.06%)	16 (25.81%)	**20 (32.26%)**	18 (29.03%)	62	3.73 / 5 (74.60%)

Appendix D: AHP pairwise judgements matrices

Table D.1 Aggregated pairwise judgement matrix for criteria with respect to the goal

GOAL	**A**	**B**	**C**	**D**	**E**	**F**	**Priority**
A Technical	1	3.08	1.32	3.08	4.53	2.94	0.2931
B Infrastructure	0.32	1	4.09	2.94	3.16	3.56	0.2473
C Economic	0.76	0.24	1	4.09	7.94	8.49	0.2758
D Social	0.32	0.34	0.24	1	1.19	1.19	0.0690
E Regulatory	0.22	0.32	0.13	0.84	1	1.19	0.0563
F Environmental	0.34	0.28	0.12	0.84	0.84	1	0.0584

$\lambda_{\max} = 6.84, \quad CI = 0.17, \quad RI = 1.25, \quad CR = 0.1351$

The *SuperDecisions* was used to highlight the most inconsistent entry in the above matrix. The screenshots given below illustrates the process. The highlighted entry 3.08, which refers to the comparison of the Technical criterion with respect to the Infrastructure criterion, is the most inconsistent judgment identified by the software. Thus, lowering this value to 1.31 will bring the CR of the matrix to within the 10% threshold value as shown below. Although, this process has slightly changed the priorities of the criteria and the alternatives, the alternatives' ranking remains the same with Satellite dominating in both cases followed by Microwave, Fibre and Power line.

CR = 0.1351

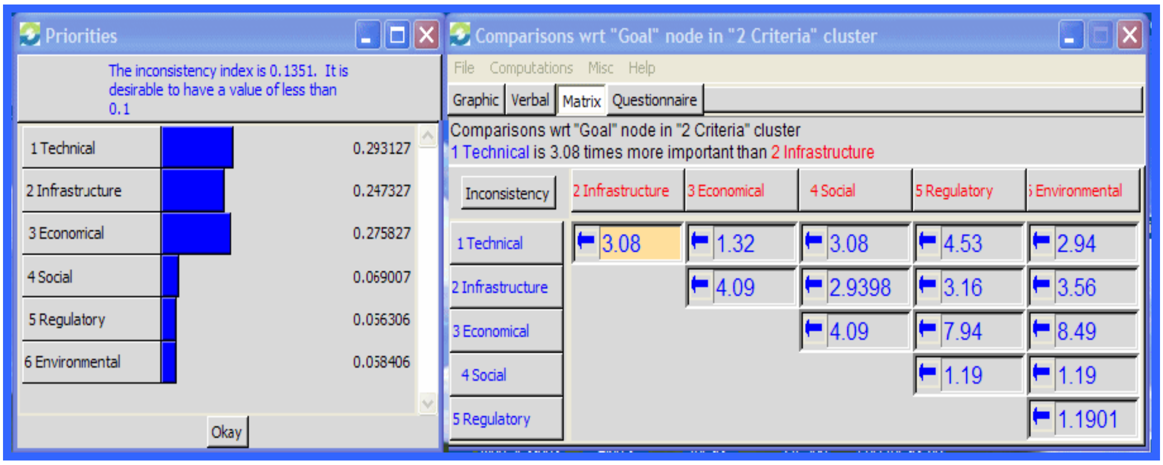


Figure D.1 A screenshot illustrating the judgements and their priorities, CR=0.1351

Table D.1.1 Alternatives' ranking when CR=0.1351

Graphic	Alternatives	Ideals	Normals	Raw	Ranking
	G1 Fibre optic	0.7878	0.2298	0.0766	3
	G2 Power line	0.6807	0.1986	0.0662	4
	G3 Microwave	0.9591	0.2798	0.0933	2
	G4 Satellite	1.0000	0.2918	0.0973	1

CR = 0.0999

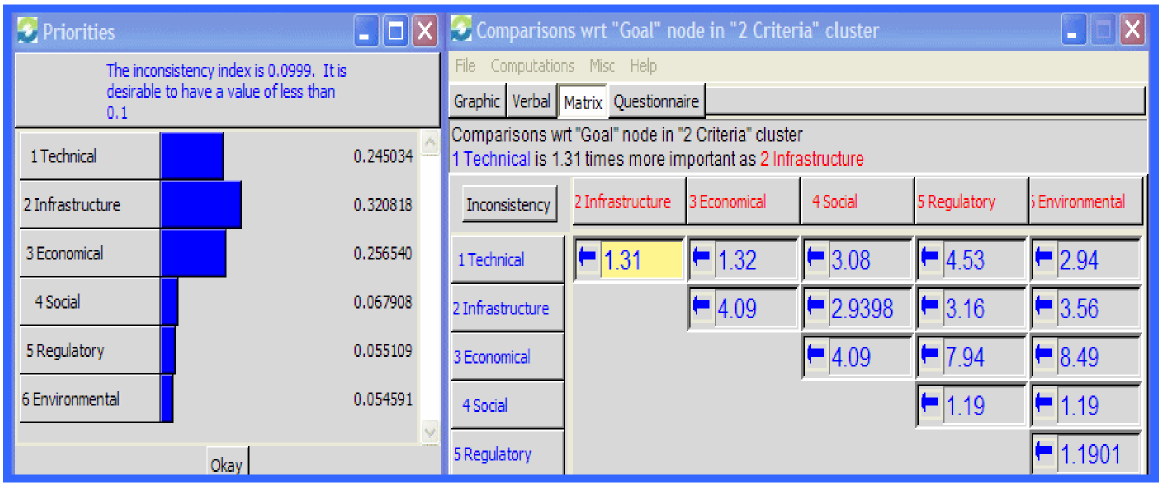


Figure D.2 A screenshot illustrating the judgements and their priorities, CR=0.0999

Table D.1.2 Alternatives' ranking when CR=0.0999

Graphic	Alternatives	Ideals	Normals	Raw	Ranking
	G1 Fibre optic	0.7533	0.2223	0.0741	3
	G2 Power line	0.7026	0.2073	0.0691	4
	G3 Microwave	0.9332	0.2754	0.0918	2
	G4 Satellite	1.0000	0.2951	0.0984	1

Table D.2 Aggregated matrices for subcriteria with respect to their criterion

A TECHNICAL	A1	A2	A3	A4	A5	A6	A7	A8	A9	Priority
A1 Reliability	1	1.22	2.91	3.23	1.82	6.05	0.98	4.9	9.67	0.2096
A2 Ease of main.	0.82	1	1.27	5.34	3.68	4.33	1	6.96	2.91	0.1981
A3 Remote ~ manage.	0.34	0.79	1	1.39	1.09	5.01	0.39	5	8	0.1222
A4 Compatibility	0.31	0.19	0.72	1	0.56	1.19	0.35	1.19	7	0.0658
A5 Ease of install	0.55	0.27	0.92	1.79	1	2.87	0.45	8.74	6.7	0.1190
A6 Scalability	0.17	0.23	0.2	0.84	0.35	1	0.18	1.79	2.01	0.0394
A7 Bandwidth	1.02	1	2.59	2.86	2.23	5.68	1	3.06	5.06	0.1850
A8 Flexibility	0.2	0.14	0.2	0.84	0.11	0.56	0.33	1	2.99	0.0371
A9 Latency	0.1	0.34	0.13	0.14	0.15	0.5	0.2	0.33	1	0.0238

$\lambda_{\max} = 9.82, \quad CI = 0.10, \quad RI = 1.45, \quad CR = 0.071$

B INFRASTRUCTURE	B1	B2	B3	B4	B5	B6	B7	B8	Priority
B1 Coverage	1	5.18	9.00	6.96	5.18	2.23	6.65	7.17	0.3719
B2 Security~ infra	0.19	1	6.88	3.31	0.89	0.20	3.08	0.19	0.0927
B3 Proposed usage	0.11	0.15	1	0.64	0.24	0.32	0.19	0.20	0.0252
B4 Avail~ technicians	0.14	0.30	1.57	1	0.38	1.67	1.00	0.32	0.0637
B5 Access ~ infra	0.19	1.12	4.12	2.65	1	0.46	1.97	0.57	0.0832
B6 Remoteness ~ area	0.45	5.00	3.08	6.00	2.19	1	3.00	1.19	0.1722
B7 Rollout time	0.15	0.32	5.14	1.00	0.51	0.33	1	0.46	0.0559
B8 Parallel infra.	0.14	5.33	5.01	3.08	1.75	0.84	2.19	1	0.1352

CR = 0.0894

C ECONOMIC	**C1**	**C2**	**C3**	**C4**	**C5**	**Priority**
C1 Operating cost	1	1.32	3.74	3.08	6.88	0.4160
C2 Funding	0.76	1	2.00	1.32	2.57	0.2310
C3 Capital cost	0.26	0.50	1	2.40	1.10	0.1448
C4 Return on investment	0.32	0.76	0.42	1	1.86	0.1261
C5 Economic ~ area	0.15	0.39	0.91	0.54	1	0.0821
						CR= 0.0561

D SOCIAL	**D1**	**D2**	**D3**	**D4**	**Priority**
D1 Demand	1	0.16	0.16	0.11	0.0404
D2 Affordability	6.40	1	0.47	0.22	0.1575
D3 Population density	6.40	2.14	1	0.21	0.2136
D4 Community of interest	8.74	4.47	4.68	1	0.5885
					***CR* = 0.0996**

E REGULATORY	**E1**	**E2**	**E3**	**Priority**
E1 Spectrum	1	0.28	0.11	0.0716
E2 Licensing constraints	3.60	1	0.30	0.2316
E3 Rights of way	8.74	3.35	1	0.6968
				***CR* = 0.0111**

F ENVIRONMENTAL	**F1**	**F2**	**Priority**
F1 Terrain topography	1	5.37	0.8415
F2 Climatic conditions	0.19	1	0.1585
			***CR* = 0.0000**

Table D.3 Aggregated matrices for alternatives with respect to each subcriterion

A1 Reliability	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	8.24	3.35	5.73	0.5707
G2 Power line	0.12	1	0.18	0.22	0.0462
G3 Microwave	0.30	5.63	1	3.83	0.2604
G4 Satellite	0.17	4.61	0.26	1	0.1227
					***CR* = 0.0958**

A2 Ease of maintenance	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.76	0.17	0.27	0.0841
G2 Power line	1.32	1	0.23	0.37	0.1126
G3 Microwave	6.05	4.36	1	1.57	0.4935
G4 Satellite	3.71	2.71	0.64	1	0.3098
					***CR* = 0.0001**

A3 Remote ~ management	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	1.41	0.37	0.27	0.1187
G2 Power line	0.71	1	0.26	0.20	0.0853
G3 Microwave	2.71	3.81	1	0.27	0.2549
G4 Satellite	3.66	5.01	3.64	1	0.5411
					***CR* = 0.0483**

A4 Compatibility	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	3.94	0.29	0.41	0.1586
G2 Power line	0.25	1	0.14	0.26	0.0568
G3 Microwave	3.48	6.96	1	4.12	0.5594
G4 Satellite	2.45	3.83	0.24	1	0.2253
					***CR* = 0.0743**

A5 Ease of Installation	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	3.66	0.41	0.17	0.1353
G2 Power line	0.27	1	0.27	0.17	0.0631
G3 Microwave	2.45	3.66	1	0.23	0.2076
G4 Satellite	5.73	5.80	4.36	1	0.5940
					***CR* = 0.0927**

A6 Scalability	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	5.85	1.32	4.86	0.4310
G2 Power line	0.17	1	0.18	0.25	0.0573
G3 Microwave	0.76	5.42	1	6.0	0.3899
G4 Satellite	0.21	3.94	0.17	1	0.1219
					***CR* = 0.0934**

A7 Bandwidth	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	6.18	3.94	8.45	0.5989
G2 Power line	0.16	1	0.21	0.76	0.0670
G3 Microwave	0.25	4.70	1	5.60	0.2653
G4 Satellite	0.12	1.32	0.18	1	0.0689
					***CR* = 0.0639**

A8 Flexibility	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	3.94	0.71	0.41	0.2041
G2 Power line	0.25	1	0.22	0.13	0.0575
G3 Microwave	1.41	4.56	1	0.71	0.2881
G4 Satellite	2.45	7.94	1.41	1	0.4503
					***CR* = 0.0039**

A9 Latency	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	1.57	4.09	9.0	0.4702
G2 Power line	0.64	1	3.25	7.54	0.3377
G3 Microwave	0.24	0.31	1	6.42	0.1523
G4 Satellite	0.11	0.13	0.16	1	0.0398
					***CR* =0.0551**

B1 Coverage	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.64	0.22	0.11	0.0584
G2 Power line	1.57	1	0.32	0.12	0.0820
G3 Microwave	4.61	3.16	1	0.44	0.2622
G4 Satellite	9.0	8.45	2.28	1	0.5974
					***CR* = 0.0048**

***B2** Security ~ infrastruc.*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.89	3.71	5.58	0.3900
G2 Power line	1.12	1	4.47	5.80	0.4369
G3 Microwave	0.27	0.22	1	1.32	0.0996
G4 Satellite	0.18	0.17	0.76	1	0.0735
					***CR* = 0.0007**

***B3** Proposed usage*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	1.41	6.18	5.80	0.4830
G2 Power line	0.71	1	4.58	4.56	0.3556
G3 Microwave	0.16	0.22	1	0.64	0.0710
G4 Satellite	0.17	0.22	1.57	1	0.0904
					***CR* = 0.0085**

***B4** Availability ~ technicns*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	1.32	7.77	5.42	0.4704
G2 Power line	0.76	1	6.05	5.01	0.3781
G3 Microwave	0.13	0.17	1	0.41	0.0546
G4 Satellite	0.18	0.20	2.45	1	0.0969
					***CR* = 0.0195**

***B5** Access of ~ infrastruc.*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.71	0.11	0.23	0.0636
G2 Power line	1.41	1	0.17	0.30	0.0901
G3 Microwave	9.0	6.0	1	1.97	0.5582
G4 Satellite	4.41	3.35	0.51	1	0.2881
					***CR* = 0.0004**

***B6** Remoteness of area*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.64	0.16	0.11	0.0525
G2 Power line	1.57	1	0.20	0.12	0.0709
G3 Microwave	6.34	4.88	1	0.51	0.3183
G4 Satellite	9.0	8.45	1.97	1	0.5583
					***CR* = 0.0073**

***B7** Rollout time*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	1.19	8.45	8.13	0.4768
G2 Power line	0.84	1	6.40	6.24	0.3820
G3 Microwave	0.12	0.16	1	3.60	0.0933
G4 Satellite	0.12	0.16	0.28	1	0.0479
					***CR* = 0.0839**

B8 *Parallel ~ infrastruc.*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	2.06	5.58	7.35	0.5332
G2 Power line	0.49	1	3.44	5.73	0.3117
G3 Microwave	0.18	0.29	1	1.19	0.0880
G4 Satellite	0.14	0.17	0.84	1	0.0671
					***CR* = 0.0095**

C1 Operating cost	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.111	0.22	0.24	0.0482
G2 Power line	9.0	1	3.81	4.36	0.5854
G3 Microwave	4.45	0.26	1	2.59	0.2253
G4 Satellite	4.24	0.23	0.39	1	0.1411
					***CR* = 0.0570**

C2 Funding	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	1.32	0.28	0.24	0.1072
G2 Power line	0.76	1	0.19	0.24	0.0824
G3 Microwave	3.60	5.18	1	2.14	0.4821
G4 Satellite	4.24	4.09	0.47	1	0.3283
					***CR* = 0.0293**

C3 *Capital cost*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.20	0.11	0.23	0.0490
G2 Power line	5.05	1	0.47	1.41	0.2446
G3 Microwave	9.0	2.14	1	3.94	0.5343
G4 Satellite	4.36	0.71	0.25	1	0.1721
					***CR* = 0.0132**

C4 *Return on investment*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.64	0.24	0.27	0.0875
G2 Power line	1.57	1	0.14	1.0	0.1221
G3 Microwave	4.21	7.17	1	4.41	0.6034
G4 Satellite	3.71	1.0	0.23	1	0.1870
					***CR* = 0.0910**

C5 *Econ. Develop ~ area*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.44	3.81	4.41	0.3075
G2 Power line	2.28	1	4.12	5.96	0.5044
G3 Microwave	0.26	0.24	1	2.45	0.1208
G4 Satellite	0.23	0.17	0.41	1	0.0673
					***CR* = 0.0395**

D1 *Demand*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	2.28	6.84	7.64	0.5536
G2 Power line	0.44	1	3.31	5.09	0.2742
G3 Microwave	0.15	0.30	1	4.05	0.1205
G4 Satellite	0.13	0.20	0.25	1	0.0517
					***CR* = 0.0668**

D2 *Affordability*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.47	0.12	0.12	0.0474
G2 Power line	2.14	1	0.17	0.20	0.0845
G3 Microwave	8.45	5.79	1	3.94	0.5743
G4 Satellite	8.13	5.05	0.25	1	0.2937
					***CR* = 0.0851**

D3 *Population density*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.64	0.23	0.13	0.0660
G2 Power line	1.57	1	0.41	0.21	0.1068
G3 Microwave	4.41	2.45	1	0.29	0.2363
G4 Satellite	7.94	4.82	3.44	1	0.5909
					***CR* = 0.0177**

D4 *Community of interest*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.17	0.49	0.13	0.0519
G2 Power line	5.73	1	7.42	0.28	0.2865
G3 Microwave	2.06	0.13	1	0.11	0.0695
G4 Satellite	7.97	3.56	9.0	1	0.5921
					***CR* = 0.0888**

E1 *Spectrum availability*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	1.0	0.13	0.11	0.0532
G2 Power line	1.0	1	0.13	0.13	0.0565
G3 Microwave	7.42	7.42	1	0.27	0.3058
G4 Satellite	8.49	7.97	3.66	1	0.5846
					***CR* = 0.0688**

E2 *Licensing constraints*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.43	2.71	5.01	0.2920
G2 Power line	2.34	1	3.46	7.33	0.5170
G3 Microwave	0.37	0.29	1	2.0	0.1280
G4 Satellite	0.20	0.13	0.50	1	0.0629
					***CR* = 0.0141**

E3 *Rights of way*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	2.83	7.11	8.49	0.5712
G2 Power line	0.35	1	4.74	7.54	0.3041
G3 Microwave	0.14	0.21	1	1.32	0.0707
G4 Satellite	0.12	0.13	0.76	1	0.0540
					***CR* = 0.0308**

F1 *Terrain topography*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.47	0.13	0.11	0.0454
G2 Power line	2.14	1	0.16	0.16	0.0790
G3 Microwave	7.71	6.16	1	0.26	0.2999
G4 Satellite	9.0	6.18	3.83	1	0.5756
					***CR* = 0.0877**

F2 Climatic conditions	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	1.97	6.85	6.82	0.5296
G2 Power line	0.51	1	4.60	4.76	0.3126
G3 Microwave	0.15	0.22	1	2.45	0.0971
G4 Satellite	0.15	0.21	0.41	1	0.0608
					***CR* = 0.0412**

Appendix E: The *SuperDecisions* software

E.1 An overview

Multi criteria analysis requires repetitive computations and could not be applied to complex network models without the use of specialised software. The impact of fast growing capabilities of modern computers is tremendous and one needs to become familiar with relevant software packages. The Super Decisions software is an appropriate package used in this study as a tool to process all the criteria related to the alternatives.

SuperDecisions was developed by William Adams working with Rozann W. Saaty (www.superdecisions.com) to solve decision problems with a network model as well as hierarchies. It is a simple easy-to-use package for constructing decision models with dependence and feedback and computing results using the supermatrices of the Analytic Network Process. This software was designed to run in many different computing environments from Windows 3.1/95/98/XP/VISAT/NT to Macintosh to UNIX systems such as Linux, SGI's, Sun Systems, etc. There is also a Web version (Adams and Saaty, 2003). A brief description about its design module will be given in this Appendix.

E.2 Building models

Models range in complexity from a single network to two-layer networks to multi-level complex networks. A full model is composed of a control network and its associated sub-networks. A simple model is a single network without a control network. Each network in a model is in a separate window. Model-building always starts with creating a simple network of clusters, elements within clusters and making links between the elements (which in turn causes a link to appear visually connecting the clusters).

E.2.1 Simple networks

Simple network means any network composed of clusters containing elements (or nodes), the links between the nodes, the links between the clusters that result from the links between the nodes, and perhaps the assessments/comparisons. A model that is comprised of a simple network has only one window. A simple network contains clusters, nodes, and connections or links. When a parent node is linked to nodes in another cluster, these are known as its children nodes. The children nodes are to be compared with respect to the parent node. When a parent node is linked to children nodes in another cluster, a line or link appears between the clusters with an arrow on it from the cluster containing the parent node. When the parent and children nodes are in the same cluster there will be a self-loop on that cluster.

Figure E.1 shows an abstract ANP model that consists of clusters, (*rather than elements arranged in levels*) nodes and arrows. The clusters hold a group of nodes which represent the decision elements. For example, A1 and A2 nodes represent the alternatives while C1 and C2 represent the criteria. The arrows define the dependencies among nodes. Two directional arrows show two-way interdependencies among elements of the network to represent their relationships with each other.

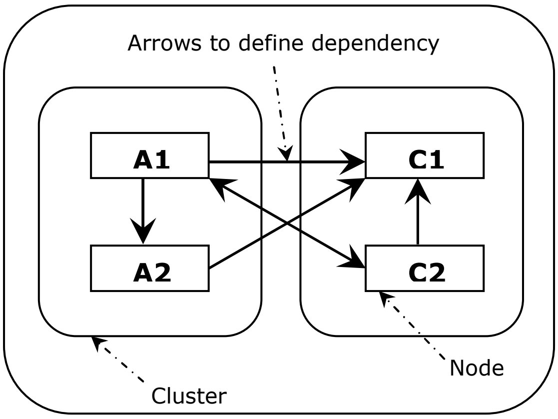


Figure E.1 An abstract ANP model as represented by *SuperDecisions*

Figure E.2 below shows how the dependencies between nodes in different clusters as well as nodes in the same cluster are represented using *SuperDecisions.* An arrow is generated between clusters to represent dependencies among nodes in different clusters 'outer dependence'. For dependencies among nodes in the same cluster 'inner dependence', the software represents it by attaching an arrow from a cluster to itself 'loop' as can be seen from the figure. This particular kind of relationships is not available in AHP models (Saaty, 1980). The pairwise comparisons are to be identified depending on the arrows that connect nodes and clusters (Adams and Saaty, 2003). From the pairwise comparison judgements; a supermatrix can be constructed based on the various sets of pairwise comparisons that are required using *SuperDecisions* software.

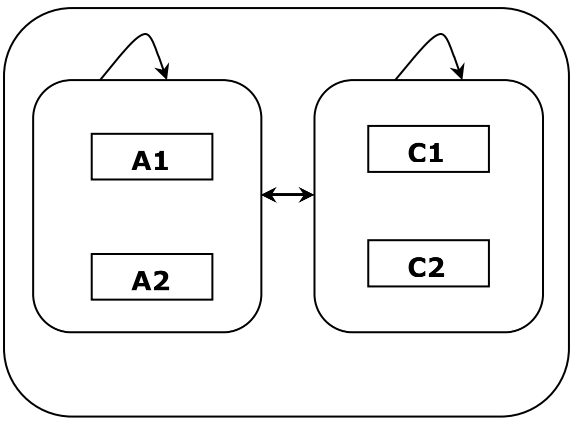


Figure E.2 Dependencies among nodes / clusters as represented by *SuperDecisions*

E.2.2 Multi-level networks

A simple network can be turned into a two-layer model by right clicking on a node in one of its clusters then selecting the Make/show subnetwork command. A three-level model can be created by selecting one of these nodes and following the same process. A subnetwork is a simple network made up of clusters, elements, connections, and comparisons just as simple networks are. Each subnetwork is in its own separate window with the name of its control node in the network "above" on its title bar. The window containing the top network in a Super Decisions model is titled the Super Decisions Main Window. Super Decisions models must have a main network and may have subnetworks, sub-subnetworks and sub-sub-sub... networks. There is no limit to the number of levels of subnetworks that can be created. However, the usual model is composed of three levels:

1. The top-level or Main network contains the Benefits, Opportunities, Costs and Risks nodes (often called the BOCR nodes).
2. Attached to each of the BOCR nodes is a subnetwork containing control criteria nodes. Not every node in the subnetwork is a control criterion node - often only those that have high priorities are chosen to become control nodes.
3. The bottom level consists of subnetworks attached to these control criteria. Such bottom level networks are often referred to as decision networks because they must have a cluster containing nodes that are the alternatives of the decision as well as other clusters.

E.2.3 Basic control networks

A control network is any network that contains nodes with subnetworks attached to them. The top level network of a full model contains merit nodes: Benefits, Opportunities, Costs and Risks, the BOCR nodes that have subnetworks attached to them. The networks in this level contain nodes known as control criteria that then have subnetworks. The criteria nodes are often general concepts such as Environmental, Social, or Political. The subnets under the control criteria are called the decision networks as they contain a cluster with the alternatives of the decision appearing as nodes in it. The networks with the control criteria in them are often hierarchical in nature with no feedback links.

In most decisions it is possible to identify the factors that offer benefits or opportunities, or have to do with costs or risks. The factors are best evaluated by grouping those that influence benefits together, and similarly grouping the others. This is done through a system of control nodes. The BOCR nodes are control nodes with networks beneath them that contain their control criteria nodes. Each of the control criteria nodes in turn has a decision subnetwork containing the alternatives of the decision.

A complete model consists of the following parts (Adams and Saaty, 2003):

1. A Rating model of personal criteria to evaluate the importance of Benefits, Opportunities, Costs and Risks in this decision;
2. A main control network containing the Merit nodes: Benefits, Opportunities, Costs and Risks, to which the importance weights from the first model are applied;
3. Subnetworks of control criteria for each of the merits;
4. The decision subnetworks that contain other factors of the problem and the alternatives. Each control criterion has a decision subnetwork.

In some complex models it becomes clear that benefits, opportunities and costs, for example, do not have equal weights in the decision. In this case it is possible to put strategic criteria in the main network to weigh up the BOCR. Personal criteria include things like growth, security, survival, and stability; things that have nothing to do directly with the problem itself, but that are important for determining the importance of the BOCR (Saaty, 2010).

E.2.4 Formulas

Formulas are needed in a top-level network of a complex model to control how the results are fed up from the bottom level networks and synthesized. Formulas are not needed in simple models consisting of a single network. Only networks that have subnetworks are allowed to have formulas. Otherwise it is a simple network that gets its synthesized priorities directly from the Limit supermatrix. Usually, the top-level control network is the only one that has a formula, although intermediate level networks may also have formulas. Any network with a formula is identified by the word formulaic on the title bar. A network is formulaic when it is a top-level network with a formula that controls how the synthesized values of the alternatives are being fed up from subnetworks attached to nodes in it and combined with priorities of nodes in the top network. Bottom level networks should not be formulaic (for there are no alternatives feeding up from lower level networks that have to be combined). Intermediate levels might be formulaic, but in general are not. The Synthesis results for the alternatives in a bottom level, or simple, network are obtained directly from the values in the limit supermatrix and presented in three ways: ideal, normalized and total (which are the raw values that appear in the limit supermatrix).

E.2.5 Making judgements / assessments

When all of the cluster and node connections have been created, one can compare/ assess nodes and clusters in each network. Nodes are compared with respect to another node and clusters are compared with respect to another cluster. Judgements/assessments are done for the nodes in each network. Nodes that form a comparison group must be in the same cluster. These nodes, the children nodes are connected from the same parent node, and are assessed with respect to how they influence that node, or how that node influences them. The parent node may be in a different cluster from the children, or the same cluster. Influence must be treated consistently, how the parent influences the children, or vice versa, but the flow direction should be kept the same throughout the network and throughout the model.

Clusters themselves may be compared as well as nodes to determine their weights. The weights of the clusters in a network add up to 1.0. If clusters are to be treated as equal and not to be compared, each is assigned a weight of 1/n where n is the number of clusters. Clusters are compared when there are three or more in the same network. Cluster comparison groups consist of the clusters linked to a particular cluster. If cluster A is linked to B, C, and D, then B, C, and D must be compared for the importance of their influence on A, or the importance of A’s influence on them. It is important to keep the influence questions parallel. It is not recommended to ask "influence on" in one comparison and "influenced by" in another one. The cluster comparisons take place in a sub-network and are done with respect to the control criterion the sub-network is attached to. To understand and facilitate the comparisons of clusters, the following should be helpful. If there are some elements in a cluster that influence some elements in another cluster, then that cluster itself must influence the other cluster.

Cluster A influences Cluster C more than Cluster B does if (Adams and Saaty, 2003):

1. A has more elements that interact more strongly with C than does B;
2. The elements in A have greater synergy and work together more than those in B;
3. The activities in A are more strongly flowing toward or influencing the activities in C; (directly and indirectly) than those in B;
4. The elements in C respond more strongly (with its use of materials, energy, purpose and operation) to the elements in A than to those in B;
5. Elements in A have more of a structural relationship with C than elements in B.

E.2.6 Supermatrix computations

Once a network is created and judgements are made, one can do computations (i.e. find out which alternatives are the best). The cluster weight matrix derived by comparing the clusters as explained in the previous section is used to weigh up the cluster blocks in the supermatrix. Before weighting the supermatrix, it is called the unweighted super matrix, which is made up of the local priority vectors obtained from the comparison groups. After weighting, it is called the weighted supermatrix where the local priority vectors in the unweighted supermatrix have been multiplied times the cluster weights. The effect of such weighting is to make the entries in an entire column in the supermatrix add up to 1.0. A matrix is a stochastic matrix when all its columns sum to one. The process of obtaining the limit matrix is to raise the weighted super matrix to powers until it stabilizes - that is, all the columns in the matrix have the same values. The Computations command is used to obtain results. All of the subcommands under the Computations command may be used to display results in a simple network that occupies a single window. The Synthesize and Sensitivity commands described below are also used to obtain results for any network that has subnetworks attached to control nodes within it.

E.2.7 Synthesising of results and sensitivity analysis

The main results of an ANP model are the overall priorities of the alternatives obtained by synthesizing the priorities of the alternatives from all the subnetworks. To get the overall results, one can use the Computations menu in the top-level model. To get intermediate results for a particular subnet, one may use the Computations menu in that subnet. Select the Computations Synthesize command to synthesize the results for the alternatives. There must be a cluster named alternatives in either that cluster, or in attached subnetworks, for there to be synthesis results. If the results are zero, probably no alternatives are included.

The synthesis command will give the priorities of the alternatives for the network where the command is invoked and all of its subnetworks, sub-subnetworks, etc. The priorities can be displayed by selecting the Computations Priorities command to determine the priorities of all the nodes in a network. They are normalized by cluster (organized by cluster with the sum of the priorities of the nodes in the cluster adding up to 1.0), and limiting with respect to the network (the sum of the priorities of all the nodes in the network adding up to 1.0). To display sensitivity graph select Computations, Sensitivity from the menu of the top level model. This is a what-if type of sensitivity that allows one to select any combination of independent variables.

Appendix F: Number of pairwise matrices in the ANP model

Table F.1 For cluster A elements and all other elements

Parent element	No. of comparison matrices	n / matrix	No. of pairwise questions
A1	1	4	6
A2	1	4	6
A3	1	4	6
A4	2	2,4	7
A5	2	2,4	7
A6	1	4	6
A7	2	3,4	9
A8	2	4,4	12
A9	1	4	6
∑	**13**	-	**65**

Table F.2 For cluster B elements and all other elements

Parent element	No. of comparison matrices	n / matrix	No. of pairwise questions
B1	3	2,2,4	8
B2	2	3,4	9
B3	1	4	6
B4	3	3,2,4	10
B5	1	4	6
B6	4	7,7,2,4	49
B7	1	4	6
B8	3	2,2,4	8
∑	**18**	-	**102**

Table F.3 For cluster C elements and all other elements

Parent element	No. of comparison matrices	n / matrix	No. of pairwise questions
C1	1	4	6
C2	1	4	6
C3	2	2,4	7
C4	1	4	6
C5	3	5,2,4	17
∑	**8**	-	**42**

Table F.4 For cluster D elements and all other elements

Parent element	No. of comparison matrices	n / matrix	No. of pairwise questions
D1	4	2,2,2,4	9
D2	1	4	6
D3	4	3,4,4,4	21
D4	2	3,4	9
∑	**11**	-	**45**

Table F.5 For cluster E elements and all other elements

Parent element	No. of comparison matrices	n / matrix	No. of pairwise questions
E1	3	3,3,4	8
E2	3	4,3,4	15
E3	3	2,2,4	8
∑	**9**	-	**31**

Table F.6 For cluster F elements and all other elements

Parent element	No. of comparison matrices	n / matrix	No. of pairwise questions
F1	5	6,5,3,2,4	35
F2	4	5,2,2,4	18
∑	**9**	-	**53**

Table F.7 For cluster G elements and all other elements

Parent element	No. of comparison matrices	n / matrix	No. of pairwise questions
G1	6	9,8,5,4,3,2	84
G2	6	9,8,5,4,3,2	84
G3	6	9,8,5,4,3,2	84
G4	6	9,8,5,4,3,2	84
∑	**24**	-	**336**

Table F.8 Total number of required pairwise comparison matrices & questions

Total	Number of comparison matrices	Number of pairwise questions
	92	**674**

Appendix G: Pairwise comparisons questionnaires

G.1 Pairwise comparisons questions for alternatives with respect to criteria

Factor: Reliability

Instructions

In selecting the more appropriate rural telecommunications backbone infrastructure to deploy e-services applications in rural areas of developing countries, given the **Reliability**, which refers to consistent speed and services within uncertain rural environments, for each pair of technologies, please:

1. *Tick (✓) which of these two technologies you believe is more reliable.*
2. *Underline the relative weighting of the technology providing more reliability relative to the technology providing less reliability, according to the scale shown in the table:*

1	*Equally reliable*	*3*	*Moderately more reliable*
5	*Strongly more reliable*	*7*	*Very Strongly more reliable*
9	*Extremely more reliable*	*2,4,6,8*	*Intermediate values*

3. *If you are not familiar with any of the factors and/or technologies, kindly skip that scale without marking.*

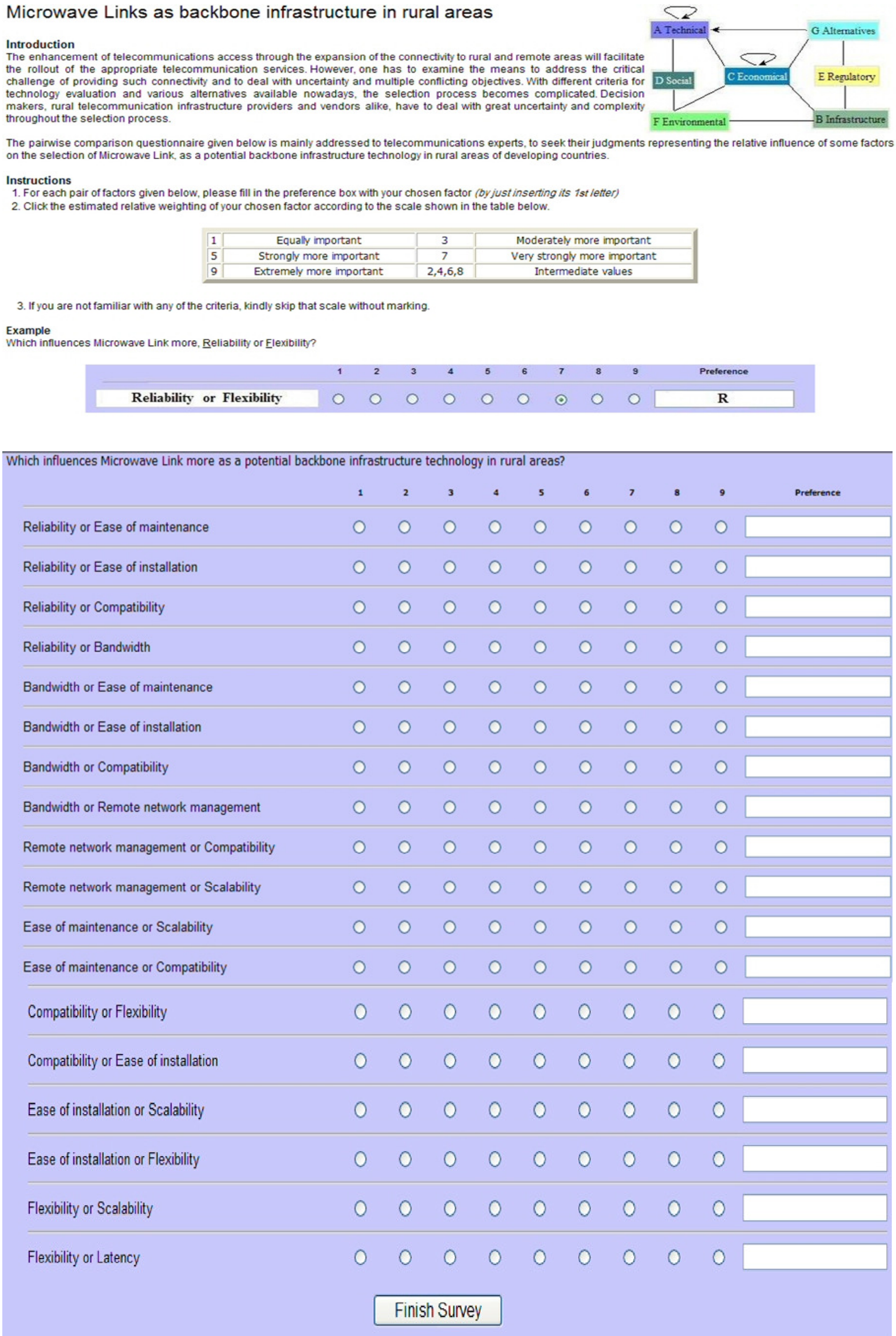
Example

Satellite ☐	**1 2 3 4 <u>5</u> 6 7 8 9**	**Fibre** ☑

For each pair of technologies given below, please complete the assessment of their relative *reliability*, as described above.

Fibre ☐	**1 2 3 4 5 6 7 8 9**	Power Line ☐
Fibre ☐	**1 2 3 4 5 6 7 8 9**	Microwave ☐
Fibre ☐	**1 2 3 4 5 6 7 8 9**	Satellite ☐
Power line ☐	**1 2 3 4 5 6 7 8 9**	Microwave ☐
Power line ☐	**1 2 3 4 5 6 7 8 9**	Satellite ☐
Microwave ☐	**1 2 3 4 5 6 7 8 9**	Satellite ☐

Due to space limitations, the other 30 factors' questionnaires, which were designed, using the same manner will be omitted. Below is a sample of an online questionnaire.



Microwave Links as backbone infrastructure in rural areas

A Technical
G Alternatives
D Social
C Economical
E Regulatory
F Environmental
B Infrastructure

Introduction
The enhancement of telecommunications access through the expansion of the connectivity to rural and remote areas will facilitate the rollout of the appropriate telecommunication services. However, one has to examine the means to address the critical challenge of providing such connectivity and to deal with uncertainty and multiple conflicting objectives. With different criteria for technology evaluation and various alternatives available nowadays, the selection process becomes complicated. Decision makers, rural telecommunication infrastructure providers and vendors alike, have to deal with great uncertainty and complexity throughout the selection process.

The pairwise comparison questionnaire given below is mainly addressed to telecommunications experts, to seek their judgments representing the relative influence of some factors on the selection of Microwave Link, as a potential backbone infrastructure technology in rural areas of developing countries.

Instructions
1. For each pair of factors given below, please fill in the preference box with your chosen factor *(by just inserting its 1st letter)*
2. Click the estimated relative weighting of your chosen factor according to the scale shown in the table below.

1	Equally important	3	Moderately more important
5	Strongly more important	7	Very strongly more important
9	Extremely more important	2,4,6,8	Intermediate values

3. If you are not familiar with any of the criteria, kindly skip that scale without marking.

Example
Which influences Microwave Link more, Reliability or Flexibility?

	1	2	3	4	5	6	7	8	9	Preference
Reliability or Flexibility	○	○	○	○	○	○	◉	○	○	R

Which influences Microwave Link more as a potential backbone infrastructure technology in rural areas?

	1	2	3	4	5	6	7	8	9	Preference
Reliability or Ease of maintenance	○	○	○	○	○	○	○	○	○	
Reliability or Ease of installation	○	○	○	○	○	○	○	○	○	
Reliability or Compatibility	○	○	○	○	○	○	○	○	○	
Reliability or Bandwidth	○	○	○	○	○	○	○	○	○	
Bandwidth or Ease of maintenance	○	○	○	○	○	○	○	○	○	
Bandwidth or Ease of installation	○	○	○	○	○	○	○	○	○	
Bandwidth or Compatibility	○	○	○	○	○	○	○	○	○	
Bandwidth or Remote network management	○	○	○	○	○	○	○	○	○	
Remote network management or Compatibility	○	○	○	○	○	○	○	○	○	
Remote network management or Scalability	○	○	○	○	○	○	○	○	○	
Ease of maintenance or Scalability	○	○	○	○	○	○	○	○	○	
Ease of maintenance or Compatibility	○	○	○	○	○	○	○	○	○	
Compatibility or Flexibility	○	○	○	○	○	○	○	○	○	
Compatibility or Ease of installation	○	○	○	○	○	○	○	○	○	
Ease of installation or Scalability	○	○	○	○	○	○	○	○	○	
Ease of installation or Flexibility	○	○	○	○	○	○	○	○	○	
Flexibility or Scalability	○	○	○	○	○	○	○	○	○	
Flexibility or Latency	○	○	○	○	○	○	○	○	○	

Finish Survey

Figure 9.6G.1 A screenshot sample of the online questionnaire

The remaining online questionnaires can be viewed by clicking on the links below.

G.2 Pairwise comparisons questions for *Criteria* with respect to *Criteria*

- Technical criteria (**54** questions), the link is:
  http://freeonlinesurveys.com/rendersurvey.asp?sid=g4mjo31ls1jewh3499469
- Infrastructure and Environmental related criteria (**60 Qs**), the link is:
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=iokrykq2rxjfpdl500136
- Economic, Social and Regulatory criteria (**72 Qs**), the link is:
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=1fk3psievcx329u500803

G.3 Pairwise comparisons questions for *Fibre* with respect to *Criteria*

- Technical criteria (**36 Qs**), the links are:
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=tn6enjm4i17b5l6534296
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=6r6bz9aksdhhrhc538022
- Infrastructure, Regulatory and Environmental criteria (**32 Qs**), the links are:
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=mqhu9xo0izdqcsd538033
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=6r2xawstpoip8md538047
- Economic and Social criteria (**16 Qs**), the link is:
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=blwl0pdxs6ubnv5538089

G.4 Pairwise comparisons questions for *Power line* with respect to *Criteria*

- Technical criteria (**36** questions), the links are:
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=fl0w1ljvp7b3s04538010
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=c8u6ueo1kkiruhm539443
- Infrastructure, Regulatory and Environmental criteria (**32 Qs**), the links are:
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=jrxxnupoggyw1a5539486
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=62dfnbzwjxgrgy9539493
- Economic and Social criteria (**16 Qs**), the link is:
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=fys127swc7o0zj2539618

G.5 Pairwise comparisons questions for *Microwave* with respect to *Criteria*

- Technical criteria (**36** questions), the links are:
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=tg8tk3xar4dgzfm538011
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=bmuoonjh526appo539444
- Infrastructure, Regulatory and Environmental criteria (**32 Qs**), the links are:
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=fjdak0hgkikpnd7539487
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=zyvhveeo3kqfulz539494
- Economic and Social criteria (**16 Qs**), the link is:
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=bnms45o8dxv3il2539619

G.6 Pairwise comparisons questions for *Satellite* with respect to *Criteria*

- Technical criteria (**36** questions), the links are:
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=e4yga4bn16he9bx538015
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=ozdc1kw41udy2l2539445
- Infrastructure, Regulatory and Environmental criteria (**32 Qs**), the links are:
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=o5jvi00hrb60grg539488
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=qazq71lp51fz9y2539495
- Economic and Social criteria (**16 Qs**), the link is:
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=75oxv95blywt1vj539620

G.7 Pairwise comparisons questions among *Criteria*

- Technical and infrastructure-related criteria, the link is:
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=bpelburds6lm0u1536883
- Economic, Social, Regulatory and Environmental criteria, the link is:
  http://FreeOnlineSurveys.com/rendersurvey.asp?sid=8kxn7r5slf0y365536862

Appendix H: Experts answers to ANP model's pairwise questions

Table H.1 Answers of pairwise questions among *Criteria*

wrt	A4	A5	A7			A8						B1		B2			B4				B6										
Experts	A2 Or A3	A2 Or A4	A1 Or A3	A1 Or A6	A3 Or A6	A2 Or A4	A2 Or A5	A2 Or A6	A4 Or A5	A4 Or A6	A5 Or A6	A3 Or A7	C3 Or C4	A1 Or A2	A1 Or A5	A2 Or A5	A1 Or A2	A1 Or A5	A2 Or A5	B3 Or B7	A1 Or A2	A1 Or A5	A1 Or A6	A1 Or A7	A1 Or A8	A1 Or A9	A2 Or A5	A2 Or A6	A2 Or A7	A2 Or A8	A2 Or A9
1	1	1	3 A1	6 A3	5 A3	5 A2	5 A2	1	1	5 A6	5 A6	3 A3	3 C4	9 A1	9 A1	1	5 A2	1	5 A2	5 B7	1	7 A5	5 A1	5 A1	5 A1	1	7 A5	5 A2	5 A2	5 A2	3 A2
2	3 A2	1	2 A1	5 A3	7 A3	4 A2	2 A2	1	3 A5	9 A6	2 A6	3 A3	4 C4	9 A1	9 A1	1	6 A2	1	7 A2	4 B7	1	9 A5	4 A1	8 A1	7 A1	2 A1	8 A5	6 A2	3 A2	3 A2	3 A2
3	1	2 A2	3 A1	9 A3	3 A3	5 A2	6 A2	1	1	2 A6	8 A6	5 A3	5 C4	8 A1	9 A1	3 A2	5 A2	1	3 A2	7 B7	2 A2	6 A5	7 A1	4 A1	3 A1	1	7 A5	5 A2	7 A2	6 A2	4 A2
4	1	1	4 A1	5 A3	6 A3	7 A2	8 A2	1	1	6 A6	7 A6	1	1	9 A1	9 A1	1	5 A2	2 A5	6 A2	5 B7	1	5 A5	3 A1	5 A1	6 A1	2 A1	7 A5	9 A2	6 A2	8 A2	2 A2
GM	**1.32**	**1.19**	**2.91**	**6.06**	**5.01**	**5.14**	**4.68**	**1.00**	**1.32**	**4.82**	**4.86**	**2.59**	**2.78**	**8.74**	**9.00**	**1.32**	**5.23**	**1.19**	**5.01**	**5.14**	**1.19**	**6.59**	**4.53**	**5.32**	**5.01**	**1.41**	**7.24**	**6.06**	**5.01**	**5.18**	**2.91**

wrt	B6																															
Experts	A5 Or A6	A5 Or A7	A5 Or A8	A5 Or A9	A6 Or A7	A6 Or A8	A6 Or A9	A7 Or A8	A7 Or A9	A8 Or A9	B1 Or B2	B1 Or B3	B1 Or B4	B1 Or B5	B1 Or B7	B1 Or B8	B2 Or B3	B2 Or B4	B2 Or B5	B2 Or B7	B2 Or B8	B3 Or B4	B3 Or B5	B3 Or B7	B3 Or B8	B4 Or B5	B4 Or B7	B4 Or B8	B5 Or B7	B5 Or B8	B7 Or B8	C1 Or C5
1	9 A5	9 A5	9 A5	7 A5	1	3 A6	3 A9	1	5 A9	5 A9	5 B1	9 B1	7 B1	5 B1	7 B1	7 B1	7 B2	3 B2	1	3 B2	3 B2	1	7 B5	5 B7	5 B8	7 B5	1	3 B8	3 B5	3 B5	1	5 C1
2	9 A5	9 A5	9 A5	4 A5	3 A6	5 A6	4 A9	1	7 A9	3 A9	6 B1	8 B1	6 B1	3 B1	7 B1	9 B1	8 B2	5 B2	2 B5	1	4 B2	3 B3	7 B5	6 B7	7 B8	7 B5	1	3 B8	4 B5	5 B5	1	5 C1
3	8 A5	9 A5	9 A5	9 A5	1	1	5 A9	1	3 A9	7 A9	8 B1	9 B1	7 B1	8 B1	5 B1	6 B1	8 B2	2 B2	1	5 B2	1	5 B3	6 B5	4 B7	6 B8	5 B5	1	5 B8	1	3 B5	1	7 C1
4	9 A5	9 A5	8 A5	8 A5	1	4 A6	2 A9	1	6 A9	5 A9	3 B1	9 B1	8 B1	6 B1	8 B1	7 B1	5 B2	4 B2	1	6 B2	7 B2	1	9 B5	5 B7	3 B8	9 B5	2 B4	2 B8	6 B5	2 B5	1	4 C1
GM	**8.74**	**9.00**	**8.74**	**6.70**	**1.32**	**2.78**	**3.31**	**1.00**	**5.01**	**4.79**	**5.18**	**8.74**	**6.96**	**5.18**	**6.65**	**7.17**	**6.88**	**3.31**	**1.19**	**3.08**	**3.03**	**1.97**	**7.17**	**4.95**	**5.01**	**6.85**	**1.19**	**3.08**	**2.91**	**3.08**	**1.00**	**5.14**

wrt	B8		C3	C5											D1			D3														
Experts	B1 Or B5	C1 Or C4	C2 Or C4	B1 Or B2	B1 Or B3	B1 Or B5	B1 Or B8	B2 Or B3	B2 Or B5	B2 Or B8	B3 Or B5	B3 Or B8	B5 Or B8	C2 Or C4	A6 Or A7	B1 Or B7	C3 Or C4	A6 Or A7	A6 Or A8	A7 Or A8	B1 Or B3	B1 Or B6	B1 Or B7	B3 Or B6	B3 Or B7	B6 Or B7	C1 Or C3	C1 Or C4	C1 Or C5	C3 Or C4	C3 Or C5	C4 Or C5
1	5 B5	3 C4	3 C4	5 B1	5 B1	5 B1	1	1	3 B5	5 B8	3 B5	5 B8	5 B8	1	1	5 B7	7 C4	7 A7	1	7 A7	4 B1	7 B1	7 B1	2 B3	1	1	7 C1	7 C1	3 C5	1	7 C5	7 C5
2	5 B5	5 C4	6 C4	5 B1	5 B1	3 B1	3 B1	2 B2	1	9 B8	5 B5	7 B8	6 B8	1	1	5 B7	9 C4	7 A7	2 A6	5 A7	1	8 B1	6 B1	5 B3	8 B3	1	7 C1	6 C1	5 C5	2 C4	5 C5	5 C5
3	6 B5	6 C4	1	4 B1	3 B1	5 B1	1	1	7 B5	3 B8	2 B5	3 B8	3 B8	1	2 A6	7 B7	5 C4	6 A7	1	7 A7	3 B1	8 B1	7 B1	3 B3	5 B3	1	6 C1	9 C1	4 C5	1	8 C5	9 C5
4	4 B5	1	4 C4	7 B1	7 B1	8 B1	1	2 B2	5 B5	6 B8	3 B5	7 B8	7 B8	3 C4	1	5 B7	7 C4	9 A7	2 A6	9 A7	3 B1	4 B1	7 B1	3 B3	6 B3	3 B6	7 C1	6 C1	2 C5	1	7 C5	6 C5
GM	**4.95**	**3.08**	**2.91**	**5.14**	**4.79**	**4.95**	**1.32**	**1.41**	**3.20**	**5.33**	**3.08**	**5.21**	**5.01**	**1.32**	**1.19**	**5.44**	**6.85**	**7.17**	**1.41**	**6.85**	**2.45**	**6.51**	**6.74**	**3.08**	**3.94**	**1.32**	**6.74**	**6.90**	**3.31**	**1.19**	**6.65**	**6.59**

wrt	D4			E1						E2									E3		F1											
Experts	B1 Or B3	B1 Or B6	B3 Or B6	A6 Or A7	A6 Or A9	A7 Or A9	B1 Or B3	B1 Or B7	B3 Or B7	A6 Or A7	A6 Or A8	A6 Or A9	A7 Or A8	A7 Or A9	A8 Or A9	B1 Or B3	B1 Or B7	B3 Or B7	A2 Or A5	B5 Or B7	A1 Or A2	A1 Or A4	A1 Or A5	A1 Or A6	A1 Or A8	A2 Or A4	A2 Or A5	A2 Or A6	A2 Or A8	A4 Or A5	A4 Or A6	A4 Or A8
1	5 B1	5 B1	2 B6	7 A7	4 A6	7 A7	7 B1	1	7 B7	3 A7	1	3 A6	1	3 A7	1	1	9 B1	7 B3	3 A5	3 B7	7 A2	5 A1	7 A5	5 A1	5 A1	9 A2	1	9 A2	9 A2	9 A5	1	1
2	5 B1	7 B1	1	9 A7	1	8 A7	6 B1	1	6 B7	4 A7	1	1	1	6 A7	1	4 B1	9 B1	4 B3	5 A5	6 B7	7 A2	6 A1	7 A5	9 A1	3 A1	8 A2	1	9 A2	9 A2	9 A5	1	2 A4
3	4 B1	5 B1	1	5 A7	3 A6	8 A7	7 B1	1	8 B7	5 A7	1	1	1	4 A7	2 A9	3 B1	8 B1	9 B3	4 A5	2 B7	6 A2	3 A1	7 A5	3 A1	5 A1	9 A2	1	9 A2	8 A2	9 A5	1	1
4	6 B1	3 B1	1	8 A7	3 A6	6 A7	8 B1	3 B1	7 B7	1	2 A6	2 A6	3 A7	1	1	5 B1	9 B1	8 B3	2 A5	3 B7	9 A2	7 A1	8 A5	4 A1	7 A1	9 A2	1	9 A2	9 A2	8 A5	1	1
GM	**4.95**	**4.79**	**1.19**	**7.09**	**2.45**	**7.20**	**6.96**	**1.32**	**6.96**	**2.78**	**1.19**	**1.57**	**1.32**	**2.91**	**1.19**	**2.78**	**8.74**	**6.70**	**3.31**	**3.22**	**7.17**	**5.01**	**7.24**	**4.82**	**4.79**	**8.74**	**1.00**	**9.00**	**8.74**	**8.74**	**1.00**	**1.19**

Table H.2 Answers of pairwise questions for *Criteria* against *Alternatives*

wrt	F1																	F2											
Experts	A5 Or A6	A5 Or A8	A6 Or A8	B1 Or B2	B1 Or B3	B1 Or B6	B1 Or B7	B2 Or B3	B2 Or B6	B2 Or B7	B3 Or B6	B3 Or B7	B6 Or B7	C1 Or C4	C1 Or C5	C4 Or C5	E1 Or E3	A1 Or A2	A1 Or A4	A1 Or A5	A1 Or A6	A2 Or A4	A2 Or A5	A2 Or A6	A4 Or A5	A4 Or A6	A5 Or A6	B6 Or B7	C1 Or C5
1	9 *A5*	9 *A5*	1	9 *B1*	9 *B1*	7 *B1*	5 *B1*	1	5 *B6*	7 *B7*	5 *B6*	7 *B7*	3 *B7*	5 *C1*	1	5 *C5*	1	3 *A1*	9 *A1*	5 *A1*	9 *A1*	5 *A2*	3 *A2*	5 *A2*	7 *A5*	1	7 *A5*	3 *B7*	7 *C1*
2	8 *A5*	9 *A5*	2 *A6*	9 *B1*	9 *B1*	8 *B1*	5 *B1*	1	7 *B6*	9 *B7*	8 *B6*	6 *B7*	3 *B7*	4 *C1*	1	8 *C5*	1	1	9 *A1*	7 *A1*	8 *A1*	5 *A2*	5 *A2*	4 *A2*	7 *A5*	1	9 *A5*	4 *B7*	8 *C1*
3	9 *A5*	9 *A5*	1	9 *B1*	8 *B1*	6 *B1*	8 *B1*	1	6 *B6*	6 *B7*	3 *B6*	6 *B7*	3 *B7*	7 *C1*	1	7 *C5*	1	2 *A1*	9 *A1*	6 *A1*	9 *A1*	7 *A2*	3 *A2*	6 *A2*	8 *A5*	2 *A4*	5 *A5*	5 *B7*	5 *C1*
4	9 *A5*	8 *A5*	1	9 *B1*	9 *B1*	8 *B1*	3 *B1*	1	3 *B6*	7 *B7*	6 *B6*	8 *B7*	4 *B7*	4 *C1*	2 *C5*	2 *C5*	1	1	9 *A1*	3 *A1*	9 *A1*	9 *A2*	2 *A2*	4 *A2*	6 *A5*	1	7 *A5*	2 *B7*	8 *C1*
GM	**8.74**	**8.74**	**1.19**	**9.00**	**8.74**	**7.20**	**4.95**	**1.00**	**5.01**	**7.17**	**5.18**	**6.70**	**3.22**	**4.86**	**1.19**	**4.86**	**1.00**	**1.57**	**9.00**	**5.01**	**8.74**	**6.30**	**3.08**	**4.68**	**6.96**	**1.19**	**6.85**	**3.31**	**6.88**

wrt	A1						A2						A3						A4						A5					
Experts	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4
1	8 *G1*	9 *G1*	6 *G1*	8 *G3*	9 *G4*	9 *G3*	1	4 *G3*	9 *G4*	5 *G3*	9 *G4*	1	2 *G1*	6 *G3*	5 *G4*	6 *G3*	2 *G4*	5 *G4*	8 *G1*	7 *G3*	4 *G4*	7 *G3*	8 *G4*	9 *G3*	4 *G1*	1	3 *G4*	4 *G3*	6 *G4*	8 *G4*
2	9 *G1*	2 *G1*	4 *G1*	6 *G3*	5 *G4*	8 *G3*	1	6 *G3*	7 *G4*	8 *G3*	1	2 *G3*	1	1	9 *G4*	5 *G3*	5 *G4*	7 *G4*	5 *G1*	3 *G3*	3 *G4*	6 *G3*	3 *G4*	1	3 *G1*	3 *G3*	9 *G4*	1	9 *G4*	1
3	8 *G1*	1	5 *G1*	3 *G3*	2 *G4*	1	3 *G2*	8 *G3*	1	1	6 *G4*	1	1	9 *G3*	1	7 *G3*	7 *G4*	1	1	7 *G3*	1	7 *G3*	1	4 *G3*	3 *G1*	4 *G3*	8 *G4*	5 *G3*	7 *G4*	5 *G4*
4	8 *G1*	7 *G1*	9 *G1*	7 *G3*	5 *G4*	3 *G3*	1	7 *G3*	3 *G4*	9 *G3*	1	3 *G3*	2 *G1*	1	4 *G4*	1	9 *G4*	5 *G4*	6 *G1*	1	3 *G4*	8 *G3*	9 *G4*	8 *G3*	5 *G1*	3 *G3*	5 *G4*	9 *G3*	3 *G4*	9 *G4*
GM	**8.24**	**3.35**	**5.73**	**5.63**	**4.61**	**3.83**	**1.32**	**6.05**	**3.71**	**4.36**	**2.71**	**1.57**	**1.41**	**2.71**	**3.66**	**3.81**	**5.01**	**3.64**	**3.94**	**3.48**	**2.45**	**6.96**	**3.83**	**4.12**	**3.66**	**2.45**	**5.73**	**3.66**	**5.80**	**4.36**

wrt	A6						A7						A8						A9						B1					
Experts	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4
1	4 *G1*	1	7 *G4*	4 *G3*	8 *G4*	9 *G3*	9 *G1*	5 *G1*	9 *G1*	5 *G3*	1	5 *G3*	3 *G1*	2 *G3*	3 *G4*	3 *G3*	7 *G4*	2 *G3*	3 *G2*	1	9 *G4*	7 *G3*	8 *G4*	9 *G4*	3 *G2*	9 *G3*	9 *G4*	5 *G3*	7 *G4*	3 *G4*
2	9 *G1*	1	8 *G4*	8 *G3*	3 *G4*	8 *G3*	9 *G1*	2 *G1*	9 *G1*	7 *G3*	1	7 *G3*	8 *G1*	1	4 *G4*	8 *G3*	9 *G4*	1	1	7 *G3*	9 *G4*	4 *G3*	5 *G4*	7 *G4*	2 *G2*	5 *G3*	9 *G4*	1	9 *G4*	3 *G4*
3	9 *G1*	1	5 *G4*	9 *G3*	2 *G4*	9 *G3*	9 *G1*	3 *G1*	9 *G1*	7 *G3*	1	7 *G3*	5 *G1*	2 *G3*	1	9 *G3*	9 *G4*	1	2 *G2*	8 *G3*	9 *G4*	2 *G3*	9 *G4*	9 *G4*	1	2 *G3*	9 *G4*	5 *G3*	9 *G4*	3 *G4*
4	3 *G1*	3 *G3*	2 *G4*	3 *G3*	5 *G4*	2 *G3*	2 *G1*	8 *G1*	7 *G1*	2 *G3*	3 *G4*	4 *G3*	2 *G1*	1	3 *G4*	2 *G3*	7 *G4*	2 *G3*	1	5 *G3*	9 *G4*	2 *G3*	9 *G4*	3 *G4*	1	5 *G3*	9 *G4*	4 *G3*	9 *G4*	1
GM	**5.58**	**1.32**	**4.86**	**5.42**	**3.94**	**6.00**	**6.18**	**3.94**	**8.45**	**4.70**	**1.32**	**5.60**	**3.94**	**1.41**	**2.45**	**4.56**	**7.94**	**1.41**	**1.57**	**4.09**	**9.00**	**3.25**	**7.54**	**6.42**	**1.57**	**4.61**	**9.00**	**3.16**	**8.45**	**2.28**

wrt	B2						B3						B4						B5						B6					
Experts	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4
1	1	1	3 *G1*	5 *G2*	6 *G2*	1	1	9 *G1*	7 *G1*	9 *G3*	8 *G4*	1	2 *G1*	9 *G1*	8 *G1*	8 *G2*	7 *G2*	3 *G4*	2 *G2*	9 *G3*	9 *G1*	9 *G3*	1	5 *G3*	1	9 *G3*	9 *G4*	9 *G3*	9 *G4*	5 *G4*
2	1	7 *G1*	9 *G1*	4 *G2*	9 *G2*	2 *G3*	2 *G1*	9 *G1*	9 *G1*	7 *G3*	6 *G4*	1	1	9 *G1*	4 *G1*	6 *G2*	5 *G2*	4 *G4*	1	9 *G3*	6 *G1*	8 *G3*	7 *G4*	1	2 *G2*	4 *G3*	9 *G4*	7 *G3*	9 *G4*	1
3	2 *G2*	3 *G1*	4 *G1*	5 *G2*	7 *G2*	1	1	2 *G1*	2 *G1*	1	3 *G4*	2 *G3*	1	9 *G1*	3 *G1*	4 *G2*	2 *G2*	3 *G4*	1	9 *G3*	1	2 *G3*	2 *G4*	3 *G3*	1	5 *G3*	9 *G4*	1	7 *G4*	3 *G4*
4	1	9 *G1*	9 *G1*	4 *G2*	3 *G2*	1	2 *G1*	9 *G1*	9 *G1*	7 *G3*	3 *G4*	3 *G3*	1	5 *G1*	9 *G1*	7 *G2*	9 *G2*	1	2 *G2*	9 *G3*	7 *G1*	9 *G3*	9 *G4*	1	3 *G2*	9 *G3*	9 *G4*	9 *G3*	9 *G4*	1
GM	**1.19**	**3.71**	**5.58**	**4.47**	**5.80**	**1.32**	**1.41**	**6.18**	**5.80**	**4.58**	**4.56**	**1.57**	**1.32**	**7.77**	**5.42**	**6.05**	**5.01**	**2.45**	**1.41**	**9.00**	**4.41**	**6.00**	**3.35**	**1.97**	**1.57**	**6.34**	**9.00**	**4.88**	**8.45**	**1.97**

wrt	B7						B8						C1						C2						C3					
Experts	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4
1	1	7 *G1*	6 *G1*	7 *G2*	7 *G2*	8 *G3*	3 *G1*	9 *G1*	9 *G1*	7 *G2*	6 *G2*	1	9 *G2*	7 *G3*	9 *G4*	1	2 *G2*	5 *G3*	1	8 *G3*	9 *G4*	4 *G3*	8 *G4*	7 *G3*	9 *G2*	9 *G3*	9 *G4*	7 *G3*	1	6 *G4*
2	1	9 *G1*	9 *G1*	8 *G2*	8 *G2*	7 *G3*	2 *G1*	6 *G1*	4 *G1*	5 *G2*	4 *G2*	2 *G3*	9 *G2*	1	6 *G4*	5 *G2*	6 *G2*	3 *G3*	2 *G1*	1	9 *G4*	6 *G3*	7 *G4*	1	8 *G2*	9 *G3*	8 *G4*	1	2 *G4*	8 *G4*
3	2 *G1*	9 *G1*	9 *G1*	5 *G2*	3 *G2*	1	1	9 *G1*	9 *G1*	2 *G2*	5 *G2*	1	9 *G2*	8 *G3*	1	7 *G2*	5 *G2*	3 *G3*	1	3 *G3*	4 *G4*	6 *G3*	5 *G4*	3 *G3*	9 *G2*	9 *G3*	5 *G4*	3 *G3*	1	5 *G4*
4	1	9 *G1*	9 *G1*	6 *G2*	9 *G2*	3 *G3*	3 *G1*	2 *G1*	9 *G1*	2 *G2*	9 *G2*	1	9 *G2*	7 *G3*	6 *G4*	6 *G2*	6 *G2*	1	1	7 *G3*	1	5 *G3*	1	1	1	9 *G3*	1	1	2 *G4*	1
GM	**1.19**	**8.45**	**8.13**	**6.40**	**6.24**	**3.60**	**2.06**	**5.58**	**7.35**	**3.44**	**5.73**	**1.19**	**9.00**	**4.45**	**4.24**	**3.81**	**4.36**	**2.59**	**1.32**	**3.60**	**4.24**	**5.18**	**4.09**	**2.14**	**5.05**	**9.00**	**4.36**	**2.14**	**1.41**	**3.94**

wrt	C4						C5						D1						D2						D3					
Experts	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4
1	3 *G2*	9 *G3*	9 *G4*	9 *G3*	1	9 *G3*	3 *G2*	7 *G1*	9 *G1*	9 *G2*	6 *G2*	3 *G3*	3 *G1*	9 *G3*	7 *G1*	8 *G2*	6 *G2*	3 *G3*	1	9 *G3*	9 *G4*	7 *G3*	6 *G4*	6 *G3*	1	9 *G3*	7 *G4*	4 *G3*	5 *G4*	7 *G4*
2	1	7 *G3*	7 *G4*	7 *G3*	1	7 *G3*	1	6 *G1*	7 *G1*	1	6 *G2*	4 *G3*	3 *G1*	9 *G1*	9 *G1*	1	8 *G2*	6 *G3*	1	9 *G3*	9 *G4*	8 *G3*	9 *G4*	1	2 *G2*	6 *G3*	9 *G4*	3 *G3*	9 *G4*	5 *G4*
3	1	1	3 *G4*	7 *G3*	1	2 *G3*	3 *G2*	5 *G1*	1	4 *G2*	5 *G2*	1	3 *G1*	9 *G1*	9 *G1*	5 *G2*	2 *G2*	5 *G3*	3 *G2*	7 *G3*	9 *G4*	4 *G3*	2 *G4*	5 *G3*	3 *G2*	1	9 *G4*	1	2 *G4*	2 *G4*
4	2 *G2*	5 *G3*	1	6 *G3*	1	3 *G3*	3 *G2*	1	6 *G1*	8 *G2*	7 *G2*	3 *G3*	1	3 *G1*	6 *G1*	3 *G2*	7 *G2*	3 *G3*	7 *G2*	9 *G3*	6 *G4*	5 *G3*	6 *G4*	8 *G3*	1	7 *G3*	7 *G4*	3 *G3*	6 *G4*	2 *G4*
GM	**1.57**	**4.21**	**3.71**	**7.17**	**1.00**	**4.41**	**2.28**	**3.81**	**4.41**	**4.12**	**5.96**	**2.45**	**2.28**	**6.84**	**7.64**	**3.31**	**5.09**	**4.05**	**2.14**	**8.45**	**8.13**	**5.79**	**5.05**	**3.94**	**1.57**	**4.41**	**7.94**	**2.45**	**4.82**	**3.44**

wrt	D4						E1						E2						E3						F1					
Experts	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4	G1 Or G2	G1 Or G3	G1 Or G4	G2 Or G3	G2 Or G4	G3 Or G4
1	9 *G2*	3 *G3*	7 *G4*	9 *G2*	1	9 *G4*	1	9 *G3*	9 *G4*	9 *G3*	9 *G4*	5 *G4*	6 *G2*	1	7 *G1*	3 *G2*	9 *G2*	5 *G3*	8 *G1*	8 *G1*	8 *G1*	9 *G2*	9 *G2*	1	7 *G2*	7 *G3*	9 *G4*	4 *G3*	6 *G4*	8 *G4*
2	4 *G2*	2 *G3*	8 *G4*	7 *G2*	5 *G4*	9 *G4*	1	6 *G3*	8 *G4*	7 *G3*	8 *G4*	1	5 *G2*	6 *G1*	3 *G1*	6 *G2*	8 *G2*	1	1	8 *G1*	9 *G1*	1	8 *G2*	2 *G3*	1	9 *G3*	9 *G4*	5 *G3*	9 *G4*	9 *G4*
3	6 *G2*	3 *G3*	9 *G4*	6 *G2*	4 *G4*	9 *G4*	1	7 *G3*	8 *G4*	6 *G3*	7 *G4*	6 *G4*	1	9 *G1*	5 *G1*	8 *G2*	8 *G2*	3 *G3*	1	8 *G1*	8 *G1*	8 *G2*	9 *G2*	1	3 *G2*	7 *G3*	9 *G4*	9 *G3*	3 *G4*	1
4	5 *G2*	1	8 *G4*	8 *G2*	8 *G4*	9 *G4*	1	8 *G3*	9 *G4*	8 *G3*	8 *G4*	6 *G4*	1	1	6 *G1*	1	5 *G2*	1	8 *G1*	5 *G1*	9 *G1*	7 *G2*	5 *G2*	1	1	8 *G3*	9 *G4*	8 *G3*	9 *G4*	3 *G4*
GM	**5.73**	**2.06**	**7.97**	**7.42**	**3.56**	**9.00**	**1.00**	**7.42**	**8.49**	**7.42**	**7.97**	**3.66**	**2.34**	**2.71**	**5.01**	**3.46**	**7.33**	**1.97**	**2.83**	**7.11**	**8.49**	**4.74**	**7.54**	**1.32**	2.14	7.71	9.00	6.16	6.18	3.83

Table H.3 Answers of pairwise questions for *Fibre* against *Criteria*

Experts	1	2	3	4	GM
A1 Or A2	1	2 A1	1	1	**1.19**
A1 or A3	3 A1	1	2 A1	4 A1	**2.21**
A1 or A4	5 A1	3 A1	2 A1	1	**2.34**
A1 or A5	8 A1	5 A1	1	4 A1	**3.56**
A1 or A6	1	7 A1	1	3 A1	**2.14**
A1 or A7	2 A7	1	7 A7	4 A7	**2.74**
A1 or A8	8 A1	5 A1	6 A1	7 A1	**6.40**
A1 or A9	8 A1	7 A1	7 A1	7 A1	**7.24**
A2 or A3	1	2 A3	1	1	**1.32**
A2 or A4	7 A4	6 A4	7 A4	8 A4	**6.96**
A2 or A5	5 A2	1	1	3 A2	**1.97**
A2 or A6	3 A6	3 A6	3 A6	1	**2.28**
A2 or A7	8 A7	9 A7	4 A7	6 A7	**6.45**
A2 or A8	6 A2	8 A2	7 A2	7 A2	**6.96**
A2 or A9	7 A9	5 A9	6 A9	5 A9	**5.69**
A3 or A4	7 A3	6 A3	1	4 A3	**3.60**
A3 or A5	2 A3	1	3 A3	3 A3	**2.06**
A3 or A6	1	3 A6	5 A6	1	**1.97**
A3 or A7	8 A7	9 A7	1	5 A7	**4.36**
A3 or A8	3 A3	1	2 A3	3 A3	**2.06**
A3 or A9	9 A9	8 A9	7 A9	6 A9	**7.42**
A4 or A5	2 A4	1	2 A4	3 A4	**1.86**
A4 or A6	1	1	1	1	**1.00**
A4 or A7	4 A7	5 A7	7 A7	5 A7	**5.14**
A4 or A8	8 A4	7 A4	5 A4	6 A4	**6.40**
A4 or A9	8 A9	9 A9	7 A9	9 A9	**8.21**
A5 or A6	1	2 A6	1	3 A6	**1.57**
A5 or A7	7 A7	9 A7	5 A7	6 A7	**6.59**
A5 or A8	3 A8	2 A8	1	3 A8	**2.06**
A5 or A9	8 A9	1	5 A9	4 A9	**3.56**
A6 or A7	9 A7	9 A7	9 A7	9 A7	**9.00**
A6 or A8	6 A8	4 A8	5 A8	5 A8	**4.95**
A6 or A9	6 A9	8 A9	7 A9	7 A9	**6.96**
A7 or A8	9 A7	9 A7	9 A7	8 A7	**8.74**
A7 or A9	7 A7	8 A7	9 A7	8 A7	**7.97**
A8 or A9	4 A9	3 A9	1	3 A9	**2.45**

Experts	1	2	3	4	GM
B1 Or B2	2 B1	4 B1	1	7 B1	**2.74**
B1 or B3	7 B1	5 B1	5 B1	5 B1	**5.44**
B1 or B4	9 B1	7 B1	9 B1	8 B1	**8.21**
B1 or B5	7 B1	7 B1	7 B1	7 B1	**7.00**
B1 or B6	1	1	1	1	**1.00**
B1 or B7	1	3 B7	1	1	**1.32**
B1 or B8	7 B1	7 B1	9 B1	9 B1	**7.94**
B2 or B3	1	2 B3	1	1	**1.19**
B2 or B4	3 B2	3 B2	3 B2	1	**2.28**
B2 or B5	4 B2	5 B2	7 B2	5 B2	**5.14**
B2 or B6	7 B6	1	1	6 B6	**2.55**
B2 or B7	8 B7	5 B7	7 B7	9 B7	**7.09**
B2 or B8	4 B2	9 B2	5 B2	7 B2	**5.96**
B3 or B4	5 B3	9 B3	5 B3	3 B3	**5.10**
B3 or B5	7 B3	9 B3	7 B3	6 B3	**7.17**
B3 or B6	5 B6	5 B6	5 B6	7 B6	**5.44**
B3 or B7	9 B7	5 B1	7 B7	6 B7	**6.59**
B3 or B8	9 B3	5 B3	7 B3	5 B3	**6.30**
B4 or B5	3 B4	1	1	1	**1.32**
B4 or B6	4 B6	5 B6	8 B6	5 B6	**5.32**
B4 or B7	5 B7	4 B7	5 B7	7 B7	**5.14**
B4 or B8	2 B8	1	1	1	**1.19**
B5 or B6	4 B6	7 B6	5 B6	8 B6	**5.79**
B5 or B7	7 B7	7 B7	9 B7	8 B7	**7.71**
B5 or B8	3 B8	1	1	1	**1.32**
B6 or B7	1	2 B7	1	3 B7	**1.57**
B6 or B8	8 B6	9 B6	9 B6	7 B6	**8.21**
B7 or B8	7 B7	8 B7	7 B7	6 B7	**6.96**

Experts	1	2	3	4	GM
C1 Or C2	8 C1	7 C1	5 C1	6 C1	**6.40**
C1 or C3	6 C1	9 C1	5 C1	6 C1	**6.34**
C1 or C4	1	7 C1	5 C1	3 C1	**3.20**
C1 or C5	7 C1	7 C1	7 C1	7 C1	**7.00**
C2 or C3	1	2 C2	1	3 C2	**1.57**
C2 or C4	1	1	2 C2	1	**1.19**
C2 or C5	5 C2	9 C2	4 C2	7 C2	**5.96**
C3 or C4	1	2 C3	1	1	**1.32**
C3 or C5	7 C3	1	3 C3	4 C3	**3.03**
C4 or C5	6 C4	6 C4	1	5 C4	**3.66**
D1 or D2	2 D1	1	7 D1	5 D1	**2.89**
D1 or D3	9 D1	7 D1	7 D1	5 D1	**6.85**
D1 or D4	4 D1	7 D1	6 D1	4 D1	**5.09**
D2 or D3	5 D2	9 D2	6 D2	6 D2	**6.34**
D2 or D4	5 D2	7 D2	5 D2	2 D2	**4.33**
D3 or D4	1	2 D3	1	1	**1.32**
E1 or E2	2 E1	1	1	1	**1.19**
E1 or E3	7 E1	5 E1	3 E1	5 E1	**4.79**
E2 or E3	5 E2	3 E2	4 E2	8 E2	**4.68**
F1 or F2	7 F1	9 F1	9 F1	8 F1	**8.21**

Table H.4 Answers of pairwise questions for *Power line* against *Criteria*

Experts	A1 Or A2	A1 or A3	A1 or A4	A1 or A5	A1 or A6	A1 or A7	A1 or A8	A1 or A9	A2 or A3	A2 or A4	A2 or A5	A2 or A6
1	1	1	4 *A4*	5 *A5*	4 *A6*	1	6 *A8*	9 *A1*	2 *A2*	8 *A4*	7 *A6*	2 *A2*
2	2 *A2*	1	3 *A4*	7 *A5*	6 *A6*	2 *A1*	5 *A8*	5 *A1*	2 *A2*	2 *A4*	4 *A5*	4 *A6*
3	1	2 *A3*	3 *A4*	3 *A5*	3 *A6*	1	5 *A8*	7 *A1*	1	6 *A4*	5 *A5*	5 *A6*
4	2 *A2*	1	5 *A4*	7 *A5*	5 *A6*	3 *A1*	9 *A8*	8 *A1*	1	7 *A4*	6 *A5*	5 *A6*
GM	**1.41**	**1.32**	**3.66**	**5.21**	**4.36**	**1.57**	**6.06**	**7.09**	**1.41**	**5.09**	**5.38**	**4.95**

Experts	A2 or A7	A2 or A8	A2 or A9	A3 or A4	A3 or A5	A3 or A6	A3 or A7	A3 or A8	A3 or A9	A4 or A5	A4 or A6	A4 or A7
1	2 *A2*	8 *A8*	5 *A2*	9 *A4*	4 *A5*	8 *A6*	1	7 *A8*	3 *A3*	1	1	7 *A4*
2	1	7 *A8*	9 *A2*	3 *A4*	3 *A5*	6 *A6*	2 A7	5 *A8*	3 *A3*	2 *A4*	1	3 *A4*
3	1	5 *A8*	3 *A2*	7 *A4*	3 *A5*	7 *A6*	1	6 *A8*	4 *A3*	1	2 A4	5 *A4*
4	1	9 *A8*	6 *A2*	5 *A4*	1	5 *A6*	3 A7	4 *A8*	5 *A3*	3 *A4*	1	7 *A4*
GM	**1.32**	**7.09**	**5.33**	**5.54**	**2.45**	**6.40**	**1.57**	**5.38**	**3.66**	**1.57**	**1.19**	**5.21**

Experts	A4 or A8	A4 or A9	A5 or A6	A5 or A7	A5 or A8	A5 or A9	A6 or A7	A6 or A8	A6 or A9	A7 or A8	A7 or A9	A8 or A9
1	4 *A4*	7 *A4*	2 A6	9 *A5*	3 *A5*	9 *A5*	9 *A6*	5 *A6*	8 *A6*	8 *A8*	8 *A7*	4 *A8*
2	4 *A4*	6 *A4*	1	7 *A5*	2 *A5*	7 *A5*	8 *A6*	6 *A6*	7 *A6*	9 *A8*	2 *A7*	3 *A8*
3	3 *A4*	9 *A4*	1	9 *A5*	4 *A5*	5 *A5*	9 *A6*	3 *A6*	9 *A6*	9 *A8*	3 *A7*	6 *A8*
4	7 *A4*	7 *A4*	1	8 *A5*	1	7 *A5*	8 *A6*	7 *A6*	7 *A6*	8 *A8*	9 *A7*	3 *A8*
GM	**4.28**	**7.17**	**1.19**	**8.21**	**2.21**	**6.85**	**8.49**	**5.01**	**7.71**	**8.49**	**4.56**	**3.83**

Experts	B1 Or B2	B1 or B3	B1 or B4	B1 or B5	B1 or B6	B1 or B7	B1 or B8	B2 or B3	B2 or B4	B2 or B5	B2 or B6	B2 or B7	B2 or B8	B3 or B4
1	2 *B2*	3 *B3*	9 *B4*	1	1	7 *B1*	9 *B8*	7 *B3*	1	3 *B5*	5 *B6*	7 *B2*	3 *B8*	6 *B3*
2	1	6 *B3*	6 *B4*	3 B5	1	9 *B1*	5 *B8*	7 *B3*	3 *B2*	2 *B5*	1	9 *B2*	5 *B8*	5 *B3*
3	2 *B2*	5 *B3*	5 *B4*	1	1	9 *B1*	7 *B8*	8 *B3*	5 *B2*	3 *B5*	3 *B6*	9 *B2*	5 *B8*	7 *B3*
4	1	3 *B3*	4 *B4*	1	2 *B6*	6 *B1*	7 *B8*	6 *B3*	1	1	1	6 *B2*	7 *B8*	5 *B3*
GM	**1.41**	**4.05**	**5.73**	**1.32**	**1.19**	**7.64**	**6.85**	**6.96**	**1.97**	**2.06**	**1.97**	**7.64**	**4.79**	**5.69**

Experts	B3 or B5	B3 or B6	B3 or B7	B3 or B8	B4 or B5	B4 or B6	B4 or B7	B4 or B8	B5 or B6	B5 or B7	B5 or B8	B6 or B7	B6 or B8	B7 or B8
1	3 *B3*	2 *B3*	6 *B3*	8 *B8*	7 *B5*	5 *B6*	5 *B4*	5 *B8*	1	8 *B5*	7 *B8*	3 *B6*	7 *B8*	9 *B8*
2	1	1 *B3*	7 *B3*	4 *B8*	5 *B5*	5 *B6*	2 *B4*	7 *B8*	1	5 *B5*	5 *B8*	3 *B6*	4 *B8*	9 *B8*
3	1	1 *B3*	8 *B3*	5 *B8*	9 *B5*	7 *B6*	3 *B4*	8 *B8*	1	8 *B5*	7 *B8*	7 *B6*	7 *B8*	9 *B8*
4	1	1 *B3*	6 *B3*	6 *B8*	6 *B5*	7 *B6*	3 *B4*	9 *B8*	3 *B6*	5 *B5*	7 *B8*	7 *B6*	4 *B8*	9 *B8*
GM	**1.32**	**1.19**	**6.70**	**5.57**	**6.59**	**5.92**	**3.08**	**7.09**	**1.32**	**6.32**	**6.44**	**4.58**	**5.29**	**9.00**

Experts	C1 Or C2	C1 or C3	C1 or C4	C1 or C5	C2 or C3	C2 or C4	C2 or C5	C3 or C4	C3 or C5	C4 or C5
1	6 C2	6 C3	6 C4	2 C5	7 C3	1	1	4 C3	4 C3	1
2	5 C2	5 C3	3 C4	4 C5	4 C3	1	2 C5	3	5 C3	1
3	9 C2	7 C3	1	7 C5	9 C3	2 *C2*	1	1	1	2 C4
4	6 C2	8 C3	8 C4	1	5 C3	1	3 C5	7 C3	8 C3	1
GM	**6.34**	**6.40**	**3.46**	**2.74**	**5.96**	**1.32**	**1.57**	**3.03**	**3.56**	**1.19**

Experts	D1 or D2	D1 or D3	D1 or D4	D2 or D3	D2 or D4	D3 or D4	E1 or E2	E1 or E3	E2 or E3	F1 or F2
1	1	2 D1	2 D1	6 D2	4 D2	1	4 *E2*	9 *E3*	5 *E3*	3 *F1*
2	2 D1	5 D1	5 D1	6 D2	6 D2	2 D3	6 *E2*	9 *E3*	3 *E3*	5 *F2*
3	1	9 D1	7 D1	9 D2	7 D2	1	2 *E2*	9 *E3*	2 *E3*	3 *F1*
4	1	6 D1	5 D1	5 D2	4 D2	3 D3	7 *E2*	9 *E3*	7 *E3*	7 *F2*
GM	**1.32**	**4.82**	**4.33**	**6.34**	**5.09**	**1.57**	**4.28**	**9.00**	**3.81**	**4.21**

Table H.5 Answers of pairwise questions for *Microwave* against *Criteria*

Experts	A1 Or A2	A1 or A3	A1 or A4	A1 or A5	A1 or A6	A1 or A7	A1 or A8	A1 or A9	A2 or A3	A2 or A4	A2 or A5	A2 or A6
1	2 *A1*	4 *A1*	7 *A4*	5 *A1*	7 *A1*	1	6 *A1*	5 *A1*	3 *A3*	3 *A2*	6 *A2*	3 *A2*
2	1	1	5 *A1*	7 *A5*	5 *A1*	2 *A1*	4 *A8*	7 *A9*	2 *A2*	5 *A2*	5 *A2*	5 *A2*
3	2 *A1*	3 *A1*	9 *A1*	9 *A1*	8 *A1*	1	7 *A1*	8 *A9*	4 *A3*	4 *A2*	8 *A2*	4 *A2*
4	1	3 *A1*	3 *A1*	7 *A1*	6 *A1*	1	5 *A1*	6 *A9*	1	3 *A4*	6 *A2*	6 *A6*
GM	**1.41**	**2.45**	**5.54**	**6.85**	**6.40**	**1.32**	**5.38**	**6.40**	**2.21**	**3.66**	**6.16**	**4.36**

Experts	A2 or A7	A2 or A8	A2 or A9	A3 or A4	A3 or A5	A3 or A6	A3 or A7	A3 or A8	A3 or A9	A4 or A5	A4 or A6	A4 or A7
1	9 *A2*	2 *A2*	4 *A9*	3 *A3*	5 *A3*	5 *A6*	5 *A3*	6 *A3*	7 *A9*	2 *A4*	1	6 *A4*
2	5 *A7*	1	7 *A9*	7 *A3*	5 *A3*	5 *A3*	3 *A3*	3 *A3*	7 *A9*	1	1	7 *A4*
3	8 *A7*	3 *A2*	8 *A9*	4 *A3*	1	4 *A3*	1	4 *A3*	5 *A9*	1	1	8 *A4*
4	3 *A7*	1	6 *A9*	4 *A3*	4 *A3*	6 *A3*	1	3 *A3*	8 *A9*	2 *A4*	1	2 *A7*
GM	**5.73**	**1.57**	**6.05**	**4.28**	**3.16**	**4.95**	**1.97**	**3.83**	**6.65**	**1.41**	**1.00**	**5.09**

Experts	A4 or A8	A4 or A9	A5 or A6	A5 or A7	A5 or A8	A5 or A9	A6 or A7	A6 or A8	A6 or A9	A7 or A8	A7 or A9	A8 or A9
1	7 *A8*	8 *A9*	3 *A6*	5 *A7*	5 *A8*	4 *A9*	9 *A7*	3 *A8*	5 *A9*	3 *A7*	7 *A7*	3 *A8*
2	7 *A8*	6 *A9*	5 *A5*	7 *A7*	5 *A5*	7 *A9*	7 *A7*	7 *A8*	5 *A9*	5 *A7*	7 *A7*	7 *A8*
3	1	9 *A9*	1	8 *A7*	1	8 *A9*	8 *A7*	1	6 *A9*	1	8 *A7*	1
4	3 *A4*	5 *A9*	1	5 *A7*	3 *A5*	5 *A9*	7 *A7*	4 *A6*	4 *A9*	6 *A7*	6 *A7*	5 *A8*
GM	**3.48**	**6.82**	**1.97**	**6.12**	**2.94**	**5.79**	**7.71**	**3.03**	**4.95**	**3.08**	**6.96**	**3.20**

Experts	B1 Or B2	B1 or B3	B1 or B4	B1 or B5	B1 or B6	B1 or B7	B1 or B8	B2 or B3	B2 or B4	B2 or B5	B2 or B6	B2 or B7	B2 or B8	B3 or B4
1	5 *B1*	7 B1	3 *B1*	7 B1	5 *B6*	8 *B1*	5 *B1*	4 *B2*	3 *B2*	1	3 *B6*	8 *B2*	7 *B8*	4 *B3*
2	3 *B1*	7 *B1*	5 *B1*	5 B1	5 *B6*	9 *B1*	4 *B1*	1	1	1	1	8 *B2*	3 *B8*	3 *B4*
3	5 *B1*	7 *B1*	7 *B1*	6 B1	7 *B6*	8 *B1*	7 *B1*	3 *B2*	1 *B2*	1	1	9 *B2*	1	7 *B3*
4	5 *B1*	7 *B1*	3 *B1*	4 B1	6 *B6*	9 *B1*	6 *B1*	3 *B2*	1	1	1	9 *B2*	5 *B8*	5 *B3*
GM	**4.40**	**7.00**	**4.21**	**5.38**	**5.69**	**8.49**	**5.38**	**2.45**	**1.57**	**1.00**	**1.32**	**8.49**	**3.20**	**4.53**

Experts	B3 or B5	B3 or B6	B3 or B7	B3 or B8	B4 or B5	B4 or B6	B4 or B7	B4 or B8	B5 or B6	B5 or B7	B5 or B8	B6 or B7	B6 or B8	B7 or B8
1	7 *B5*	4 *B6*	1	5 *B3*	1	1	1	6 *B8*	7 *B6*	6 *B5*	7 *B8*	7 *B6*	7 *B6*	5 *B8*
2	9*B5*	3 *B6*	1	3 *B3*	1	1	2 *B7*	9 *B8*	3 *B6*	4 *B5*	4 *B5*	3 *B6*	2 *B6*	4 *B8*
3	5 *B5*	1	1	7 *B3*	3 *B5*	1	1	5 *B8*	1	8 *B5*	7 *B8*	5 *B6*	7 *B6*	1
4	3 *B5*	3 *B6*	1	6 *B3*	1	1	3 *B7*	7 *B8*	5 *B6*	3 *B5*	5 *B8*	6 *B6*	5 *B6*	3 *B8*
GM	**5.54**	**2.45**	**1.00**	**5.01**	**1.32**	**1.00**	**1.57**	**6.59**	**3.20**	**4.90**	**5.60**	**5.01**	**4.70**	**2.78**

Experts	C1 Or C2	C1 or C3	C1 or C4	C1 or C5	C2 or C3	C2 or C4	C2 or C5	C3 or C4	C3 or C5	C4 or C5
1	1	5 C1	5 C1	7 C5	7 C2	5 C4	7 C2	1	7 C5	1
2	1	7 C1	7 C1	1	6 C2	7 C4	7 C5	5 C4	6 C5	1
3	2 C1	8 C1	1	8 C1	8 C2	1	8 C2	7 C4	1	2 *C5*
4	1	6 C1	3 C1	3 C1	5 C2	7 C2	6 C2	3 C4	3 C5	1
GM	**1.19**	**6.40**	**3.20**	**3.60**	**6.40**	**3.96**	**6.96**	**3.20**	**3.35**	**1.32**

Experts	D1 or D2	D1 or D3	D1 or D4	D2 or D3	D2 or D4	D3 or D4	E1 or E2	E1 or E3	E2 or E3	F1 or F2
1	7 D1	6 D1	9 D1	7 D2	5 D2	5 D3	7 E1	9 E1	7 E2	8 *F1*
2	5 D1	7 D1	9 D1	1	2 D2	2 D3	1	9 E1	6 E2	5 *F1*
3	8 D1	8 D1	8 D1	3 D2	8 D2	8 D3	8 E1	8 E1	1	3 *F1*
4	6 D1	5 D1	9 D1	1	5 D2	6 D3	3 E1	9 E1	3 E2	7 *F1*
GM	**6.40**	**6.40**	**8.74**	**2.14**	**4.47**	**4.68**	**3.60**	**8.74**	**3.35**	**5.38**

Table H.6 Answers of pairwise questions for *Satellite* against *Criteria*

Experts	A1 Or A2	A1 or A3	A1 or A4	A1 or A5	A1 or A6	A1 or A7	A1 or A8	A1 or A9	A2 or A3	A2 or A4	A2 or A5	A2 or A6	A2 or A7	A2 or A8	A2 or A9	A3 or A4	A3 or A5	A3 or A6
1	3 *A1*	8 *A3*	2 *A1*	7 *A1*	8 *A1*	3 *A1*	6 *A1*	7 *A9*	1	3 *A2*	1	3 *A2*	1	6 *A2*	9 *A9*	3 *A3*	3 *A3*	2 *A3*
2	1	5 *A3*	7 *A1*	4 *A5*	7 *A1*	6 *A1*	7 *A1*	8 *A9*	2 *A3*	7 *A2*	2 *A2*	7 *A2*	7 *A7*	8 *A2*	7 *A9*	1	1	9 *A6*
3	1	7 *A3*	1	6 *A1*	7 *A1*	5 *A1*	5 *A1*	8 *A9*	1	5 *A2*	1	5 *A2*	2 *A7*	6 *A2*	7 *A9*	1	1	1
4	1	6 *A3*	5 *A1*	5 *A1*	9 *A1*	7 *A1*	5 *A1*	9 *A9*	2 *B7*	5 *A4*	1	3 *A2*	5 *A7*	5 *A2*	7 *A9*	1	1	7 *A6*
GM	**1.57**	**6.40**	**2.89**	**5.38**	**7.71**	**5.01**	**5.69**	**7.97**	**1.41**	**4.79**	**1.19**	**4.21**	**2.89**	**6.16**	**7.45**	**1.32**	**1.57**	**3.35**

Experts	A3 or A7	A3 or A8	A3 or A9	A4 or A5	A4 or A6	A4 or A7	A4 or A8	A4 or A9	A5 or A6	A5 or A7	A5 or A8	A5 or A9	A6 or A7	A6 or A8	A6 or A9	A7 or A8	A7 or A9	A8 or A9
1	3 *A7*	8 *A3*	5 *A9*	1	7 *A6*	1	3 *A4*	9 *A9*	5 *A6*	3 *A7*	1	7 *A9*	1	5 *A6*	8 *A9*	9 *A7*	3 *A9*	1
2	5 *A7*	4 *A3*	6 *A9*	2 *A4*	5 *A6*	9 *A7*	3 *A4*	5 *A9*	2 *A6*	6 *A7*	5 *A5*	9 *A9*	1	1	9 *A9*	7 *A7*	2 *A9*	3 *A8*
3	5 *A7*	9 *A3*	7 *A9*	1	5 *A6*	1	5 *A4*	7 *A9*	1	5 *A7*	2 *A5*	6 *A9*	1	7 *A6*	7 *A9*	7 *A7*	4 *A9*	1
4	5 *A7*	5 *A3*	5 *A9*	1	4 *A6*	7 *A7*	5 *A4*	6 *A9*	7 *A6*	7 *A7*	7 *A5*	8 *A9*	1	1	7 *A9*	8 *A7*	3 *A9*	5 *A8*
GM	**4.40**	**6.16**	**5.69**	**1.19**	**5.14**	**2.82**	**3.87**	**6.59**	**2.89**	**5.01**	**2.89**	**7.42**	**1.00**	**2.43**	**7.71**	**7.71**	**2.91**	**1.97**

Experts	B1 Or B2	B1 or B3	B1 or B4	B1 or B5	B1 or B6	B1 or B7	B1 or B8	B2 or B3	B2 or B4	B2 or B5	B2 or B6	B2 or B7	B2 or B8	B3 or B4	B3 or B5	B3 or B6	B3 or B7	B3 or B8	B4 or B5	B4 or B6	B4 or B7	B4 or B8	B5 or B6	B5 or B7	B5 or B8	B6 or B7	B6 or B8	B7 or B8
1	9 *B2*	3 *B3*	5 *B4*	1	1	1	9 *B8*	8 *B2*	3 *B2*	7 *B2*	8 *B2*	7 *B2*	5 *B8*	1	3 *B3*	5 *B3*	1	5 *B8*	5 *B4*	5 *B4*	7 *B4*	3 *B8*	3 *B5*	3 *B5*	9 *B8*	8 *B7*	9 *B8*	5 *B8*
2	9 *B2*	5 *B3*	5 *B4*	1	1	2 *B1*	6 *B8*	5 *B2*	1	9 *B2*	7 *B2*	5 *B2*	9 *B8*	2 *B3*	1	5 *B3*	1	3 *B8*	7 *B4*	6 *B4*	8 *B4*	1	1	1	9 *B8*	5 *B7*	9 *B8*	5 *B8*
3	9 *B2*	1	7 *B4*	1	3 *B6*	1	6 *B8*	8 *B2*	1	7 *B2*	9 *B2*	8 *B2*	4 *B8*	1	1	5 *B3*	1	7 *B8*	5 *B4*	3 *B4*	7 *B4*	5 *B8*	2 *B5*	1	9 *B8*	4 *B7*	8 *B8*	5 *B8*
4	9 *B2*	6 *B3*	5 *B4*	1	1	2 *B7*	9 *B8*	4 *B2*	1	6 *B2*	7 *B2*	9 *B2*	7 *B8*	1	5 *B3*	7 *B3*	1	5 *B8*	4 *B4*	5 *B4*	9 *B4*	6 *B8*	5 *B5*	1	9 *B8*	5 *B7*	7 *B8*	5 *B8*
GM	**9.00**	**3.08**	**5.44**	**1.00**	**1.32**	**1.41**	**7.35**	**5.98**	**1.57**	**7.17**	**7.71**	**7.09**	**5.96**	**1.19**	**1.97**	**5.44**	**1.00**	**4.79**	**5.14**	**4.61**	**7.71**	**3.08**	**2.34**	**1.32**	**9.00**	**5.32**	**8.21**	**5.00**

Experts	C1 Or C2	C1 or C3	C1 or C4	C1 or C5	C2 or C3	C2 or C4	C2 or C5	C3 or C4	C3 or C5	C4 or C5	D1 or D2	D1 or D3	D1 or D4	D2 or D3	D2 or D4	D3 or D4	E1 or E2	E1 or E3	E2 or E3	F1 or F2
1	7 *C2*	1	3 *C4*	3 *C5*	9 *C2*	1	6 *C2*	3 *C4*	3 *C5*	1	3 *D2*	3 *D3*	3 *D1*	3 *D2*	3 *D2*	1	4 *E1*	7 *E1*	9 *E2*	9 *F2*
2	6 *C2*	1	5 *C1*	5 *C5*	7 *C2*	1	7 *C2*	7 *C4*	7 *C5*	2 *C4*	5	1	3 *D1*	5 *D2*	5	9 *D4*	1	7 *E1*	5 *E2*	8 *F2*
3	1	2 C1	6 *C4*	4 *C5*	1	3 *C2*	1	5 *C4*	8 *C5*	1	4	2 *D1*	3 *D1*	7	6	8 *D4*	3 *E1*	5 *E1*	6 *E2*	5 *F1*
4	1	1	5 *C4*	4 *C5*	2 *C2*	1	3 *C2*	4 *C4*	5 *C5*	2 *C4*	3 *D2*	5 *D1*	1	5 *D2*	4 *D2*	2 *D4*	3 *E1*	8 *E1*	7 *E2*	7 *F2*
GM	**2.55**	**1.19**	**4.61**	**3.94**	**3.35**	**1.32**	**3.35**	**4.53**	**5.38**	**1.41**	**3.66**	**2.34**	**2.28**	**4.79**	**4.36**	**3.46**	**2.45**	**6.65**	**6.59**	**7.09**

Table H.7 Answers of pairwise questions among *Clusters*

Experts	*with respect to A 'Technical'*										*with respect to B 'Infrastructure'*										*with respect to C 'Economic'*		
	A Or B	A Or C	A Or D	A Or G	B Or C	B Or D	B Or G	C Or D	C Or G	D Or G	A Or B	A Or C	A Or D	A Or G	B Or C	B Or D	B Or G	C Or D	C Or G	D Or G	B Or C	B Or G	C Or G
1	3 *A*	1	3 *D*	7 *G*	1	1	7 *B*	1	9 *C*	7 *D*	2 *A*	5 *C*	1	6 *A*	9 *C*	1	9 *B*	9 *C*	9 *C*	3 *D*	2 *C*	5 *B*	8 *C*
2	1	3 *C*	5 *D*	7 *G*	7 *C*	1	1	7 *C*	9 *C*	1	1	3 *C*	3 *A*	6 *A*	4 *C*	1	8 *B*	9 *C*	9 *C*	3 *D*	1	5 *B*	8 *C*
3	5 *A*	1	1	5 *G*	8 *C*	1	3 *B*	8 *C*	9 *C*	3 *D*	3 *A*	7 *C*	1	5 *A*	9 *C*	3 *B*	1	9 *C*	9 *C*	3 *D*	3 *C*	5 *B*	8 *C*
4	6 *A*	1	6 *D*	8 *G*	5 *C*	1	1	5 *C*	9 *C*	1	1	5 *C*	5 *A*	7 *A*	9 *C*	1	3 *B*	9 *C*	9 *C*	3 *D*	1	5 *B*	8 *C*
GM	**3.08**	**1.32**	**3.08**	**6.65**	**4.09**	**1.0**	**2.14**	**4.09**	**9.0**	**2.14**	**1.57**	**4.79**	**1.97**	**5.96**	**7.35**	**1.32**	**3.83**	**9.0**	**9.0**	**3.0**	**1.57**	**5.0**	**8.0**

Experts	*with respect to D 'Social'*										*with respect to E 'Regulatory'*														
	A Or B	A Or C	A Or D	A Or G	B Or C	B Or D	B Or G	C Or D	C Or G	D Or G	A Or B	A Or C	A Or D	A Or E	A Or G	B Or C	B Or D	B Or E	B Or G	C Or D	C Or E	C Or G	D Or E	D Or G	E Or G
1	2 *A*	2 *C*	5 *A*	6 *A*	3 *C*	3 *B*	7 *B*	9 *C*	9 *C*	1	1	1	1	5 *A*	4 *A*	3 *C*	3 *B*	5 *B*	3 *B*	9 *C*	7 *C*	9 *C*	1	1	1
2	1	1	5 *A*	6 *A*	3 *C*	3 *B*	3 *B*	9 *C*	9 *C*	1	2 *A*	3 *C*	8 *A*	4 *A*	9 *A*	3 *C*	4 *B*	1	3 *B*	4 *C*	9 *C*	9 *C*	1	2 *D*	1
3	3 *A*	3 *C*	5 *A*	6 *A*	5 *C*	3 *B*	7 *B*	9 *C*	9 *C*	2 *D*	1	1	5 *A*	7 *A*	9 *A*	5 *C*	5 *B*	5 *B*	5 *B*	9 *C*	9 *C*	9 *C*	2 *D*	1	3 *E*
4	1	1	5 *A*	6 *A*	1	3 *B*	1	5 *C*	9 *C*	1	2 *A*	5 *C*	6 *A*	3 *A*	3 *A*	1	1	4 *B*	5 *B*	9 *C*	7 *C*	9 *C*	1	2 *D*	1
GM	**1.57**	**1.57**	**5.0**	**6.0**	**2.59**	**3.0**	**3.48**	**7.77**	**9.0**	**1.19**	**1.41**	**1.97**	**3.94**	**4.53**	**5.58**	**2.59**	**2.78**	**3.16**	**3.87**	**7.35**	**7.94**	**9.0**	**1.19**	**1.41**	**1.32**

Experts	*with respect to F 'Environmental'*															*with respect to G 'Alternative'*														
	A Or B	A Or C	A Or D	A Or E	A Or G	B Or C	B Or D	B Or E	B Or G	C Or D	C Or E	C Or G	D Or E	D Or G	E Or G	A Or B	A Or C	A Or D	A Or E	A Or F	B Or C	B Or D	B Or E	B Or F	C Or D	C Or E	C Or F	D Or E	D Or F	E Or F
1	1	9 *C*	1	3 *A*	4 *A*	5 *C*	1	4 *B*	5 *B*	7 *C*	9 *C*	9 *C*	1	3 *D*	2 *E*	1	3 *C*	5 *A*	3 *A*	5 *A*	6 *C*	5 *B*	1	1	7 *C*	9 *C*	9 *C*	1	1	2 *F*
2	1	8 *C*	3 *A*	3 *A*	9 *A*	4 *C*	1	1	8 *B*	4 *C*	9 *C*	9 *C*	3 *D*	3 *D*	1	1	2 *C*	1	3 *A*	5 *A*	5 *C*	5 *B*	8 *B*	5 *B*	7 *C*	9 *C*	8 *C*	2 *D*	1	1
3	3 *A*	1	1	3 *A*	9 *A*	5 *C*	3 *B*	3 *B*	1	9 *C*	8 *C*	9 *C*	1	3 *D*	3 *E*	2 *B*	3 *C*	7 *A*	3 *A*	1	1	1	5 *B*	4 *B*	7 *C*	9 *C*	8 *C*	1	2 *D*	1
4	1	3 *C*	5 *A*	4 *A*	3 *A*	7 *C*	1	3 *B*	9 *B*	8 *C*	9 *C*	9 *C*	5 *D*	4 *D*	1	1	4 *C*	1	4 *A*	3 *A*	1	3 *B*	6 *B*	8 *B*	7 *C*	9 *C*	9 *C*	2 *D*	1	1
GM	**1.32**	**3.83**	**1.97**	**3.22**	**5.58**	**5.14**	**1.32**	**2.45**	**4.36**	**6.70**	**8.74**	**9.0**	**1.97**	**3.22**	**1.57**	**1.19**	**2.91**	**2.43**	**3.22**	**2.94**	**2.34**	**2.94**	**3.94**	**3.56**	**7.0**	**9.0**	**8.49**	**1.41**	**1.19**	**1.19**

Appendix I: ANP model's pairwise comparisons judgements matrices

Table I.1 Pairwise matrices for *Criteria* with respect to *Criteria*

***A4** Compatibility*	**A2**	**A4**	**Priority**
A2 Ease of maintenance	1	1.32	0.5434
A4 Compatibility	0.76	1	0.4566
			CR = 0.00

***A5** Ease of installation*	**A2**	**A4**	**Priority**
A2 Ease of maintenance	1	1.19	0.5434
A4 Compatibility	0.84	1	0.4566
			CR = 0.00

***A7** Bandwidth*	**A1**	**A3**	**A6**	**Priority**
A1 Reliability	1	2.91	6.06	0.6315
A3 Remote ~ management	0.34	1	5.01	0.2908
A6 Scalability	0.17	0.20	1	0.0778
				CR = 0.08

***A8** Flexibility*	**A2**	**A4**	**A5**	**A6**	**Priority**
A2 Ease of maintenance	1	5.14	4.68	1.0	0.4163
A4 Compatibility	0.19	1	1.32	0.21	0.0905
A5 Ease of installation	0.21	0.76	1	0.21	0.0805
A6 Scalability	1.0	4.82	4.86	1	0.4127
					CR = 0.01

***B1** Coverage*	**A3**	**A7**	**Priority**
A3 Remote ~ management	1	2.59	0.7214
A7 Bandwidth	0.39	1	0.2786
			CR = 0.00

***B1** Coverage*	**C3**	**C4**	**Priority**
C3 Capital cost	1	036	0.2645
C4 Return ~ investments	2.78	1	0.7355
			CR = 0.00

***B2** Security ~ infrastructure*	**A1**	**A2**	**A5**	**Priority**
A1 Reliability	1	8.74	9.0	0.8153
A2 Ease of maintenance	0.11	1	1.32	0.1013
A5 Ease of installation	0.11	0.76	1	0.0834
				CR = 0.06

***B4** Availability ~ technicians*	**A1**	**A2**	**A5**	**Priority**
A1 Reliability	1	0.19	0.84	0.1201
A2 Ease of maintenance	5.23	1	5.01	0.6559
A5 Ease of installation	1.19	0.20	1	0.2240
				CR = 0.03

B4 *Availability ~ technicians*	**B3**	**B7**	**Priority**
B3 Proposed ~ usage	1	0.19	0.1629
B7 Rollout time	5.14	1	0.8371
			CR = 0.00

B6 *Remote ~ area*	**A1**	**A2**	**A5**	**A6**	**A7**	**A8**	**A9**	**Priority**
A1 Reliability	1	0.84	0.15	4.53	5.32	5.01	1.41	0.1248
A2 Ease of main.	1.19	1	0.14	6.06	5.01	5.18	2.91	0.1568
A5 Ease of install	6.59	7.24	1	8.74	9.0	8.74	6.70	0.5268
A6 Scalability	0.22	0.17	0.11	1	1.32	2.78	0.30	0.0393
A7 Bandwidth	0.19	0.20	0.11	0.76	1	1.0	0.20	0.0290
A8 Flexibility	0.20	0.20	0.11	0.36	1.0	1	0.21	0.0273
A9 Latency	0.71	0.34	0.15	3.31	5.01	4.79	1	0.0959
								CR = 0.07

B6 *Remote ~ area*	**B1**	**B2**	**B3**	**B4**	**B5**	**B7**	**B8**	**Priority**
B1 Coverage	1	5.18	8.74	6.96	5.18	6.65	7.17	0.4708
B2 Security ~ infra.	0.19	1	6.88	3.31	0.84	3.08	3.03	0.1483
B3 Proposed usage	0.11	0.15	1	1.97	0.14	0.20	0.20	0.0301
B4 Avail~ technicns	0.14	0.30	0.51	1	0.15	1.19	0.32	0.0379
B5 Access ~ infra.	0.19	1.19	7.17	6.85	1	2.91	3.08	0.1732
B7 Rollout time	0.15	0.32	4.95	0.84	0.34	1	1.0	0.0647
B8 Parallel ~ infra	0.14	0.33	5.01	3.08	0.32	1.0	1	0.0750
								CR = 0.09

B6 *Remoteness of area*	**C1**	**C5**	**Priority**
C1 Operating cost	1	5.19	0.8384
C5 Economic ~ area	0.19	1	0.1616
			CR = 0.00

B8 *Parallel infrastructure*	**B1**	**B5**	**Priority**
B1 Coverage	1	0.20	0.1680
B5 Access ~ infrastructure	4.95	1	0.8319
			CR = 0.00

B8 *Parallel infrastructure*	**C1**	**C4**	**Priority**
C1 Operating cost	1	0.32	0.2451
C4 Return on investments.	3.08	1	0.7549
			CR = 0.00

C3 *Capital cost*	**C2**	**C4**	**Priority**
C2 Funding	1	2.91	0.7442
C4 Return ~ investments	0.34	1	0.2558
			CR = 0.00

C5 *Economic develop ~ area*	**B1**	**B2**	**B3**	**B5**	**B8**	**Priority**
B1 Coverage	1	5.14	4.79	4.95	1.32	0.3956
B2 Security ~infrastructure	0.19	1	1.41	0.31	0.19	0.0619
B3 Proposed usage	0.21	0.71	1	0.32	0.19	0.0558
B5 Access ~ infrastructure	0.20	3.20	3.08	1	0.20	0.1234
B8 Parallel ~ infrastructure	0.76	5.33	5.21	5.01	1	0.3633
						CR = 0.05

C5 *Economic develop ~ area*	**C2**	**C4**	**Priority**
C2 Funding	1	0.76	0.4310
C4 Return on investments.	1.32	1	0.5690

CR = 0.00

D1 *Demand*	**B1**	**B7**	**Priority**
B1 Coverage	1	0.18	0.1553
B7 Bandwidth	5.44	1	0.8447

CR = 0.00

D1 *Demand*	**C3**	**C4**	**Priority**
C3 Capital cost	1	0.15	0.1274
C4 Return ~ invest	6.85	1	0.8726

CR = 0.00

D3 *Population density*	**A6**	**A7**	**A8**	**Priority**
A6 Scalability	1	0.14	1.41	0.1234
A7 Bandwidth	7.16	1	6.85	0.7770
A8 Flexibility	0.71	0.15	1	0.0996

CR = 0.02

D3 *Population density*	**B1**	**B2**	**B3**	**B4**	**Priority**
B1 Coverage	1	2.45	6.51	6.74	0.5725
B2 Proposed usage	0.41	1	3.08	3.94	0.2648
B3 Remote N. M.	0.15	0.32	1	1.32	0.0897
B4 Rollout time	0.15	0.25	0.76	1	0.0730

CR = 0.05

D3 *Population density*	**C1**	**C3**	**C4**	**C5**	**Priority**
C1 Operating cost	1	6.74	6.90	0.30	0.3102
C3 Capital cost	0.15	1	0.84	0.15	0.0576
C4 Return on investments.	0.14	1.19	1	0.15	0.0625
C5 Economic ~ area	3.31	6.65	6.59	1	0.5697

CR = 0.07

D4 *Community of interest*	**B1**	**B3**	**B6**	**Priority**
B1 Coverage	1	4.95	4.79	0.7084
B3 Proposed usage	0.20	1	0.84	0.1365
B6 Remoteness of area	0.21	1.19	1	0.1550

CR = 0.00

E1 *Spectrum availability*	**A6**	**A7**	**A9**	**Priority**
A6 Scalability	1	0.14	2.45	0.1463
A7 Bandwidth	7.09	1	7.20	0.7736
A9 Latency	0.41	0.14	1	0.0801

CR = 0.08

E1 *Spectrum availability*	**B1**	**B3**	**B7**	**Priority**
B1 Coverage	1	6.96	1.32	0.5097
B3 Proposed usage	0.14	1	0.14	0.0668
B7 Rollout time	0.76	6.96	1	0.2436
				CR = 0.01

E2 *Licensing constraints*	**A6**	**A7**	**A8**	**A9**	**Priority**
A6 Scalability	1	0.36	1.19	1.57	0.2083
A7 Bandwidth	2.78	1	1.32	2.91	0.4236
A8 Flexibility	0.84	0.76	1	0.84	0.2025
A9 Latency	0.64	0.34	1.19	1	0.1656
					CR = 0.05

E2 *Licensing constraints*	**B1**	**B3**	**B7**	**Priority**
B1 Coverage	1	2.78	8.74	0.6444
B3 Proposed usage	0.36	1	6.70	0.2983
B7 Rollout time	0.11	0.15	1	0.0573
				CR = 0.06

E3 *Rights of way*	**A2**	**A5**	**Priority**
A2 Ease of main.	1	3.31	0.7680
A5 Ease of install.	0.30	1	0.2320
			CR = 0.00

E3 *Rights of way*	**B5**	**B7**	**Priority**
B5 Access ~ infrastructure	1	3.22	0.7630
B7 Rollout time	0.31	1	0.2370
			CR = 0.00

F1 *Terrain topography*	**A1**	**A2**	**A4**	**A5**	**A6**	**A8**	**Priority**
A1 Reliability	1	0.14	5.01	0.13	4.82	4.79	0.1130
A2 Ease of main.	7.17	1	8.74	1.0	9.0	8.74	0.3928
A4 Compatibility	0.20	0.11	1	0.11	1.0	1.19	0.0347
A5 Ease of install.	7.24	1.0	8.74	1	8.74	8.74	0.3927
A6 Scalability	0.21	0.11	1.0	0.11	1	1.19	0.0346
A8 Flexibility	0.21	0.11	0.84	0.11	0.84	1	0.0321
							CR = 0.05

F1 *Terrain topography*	**B1**	**B2**	**B3**	**B6**	**B7**	**Priority**
B1 Coverage	1	9.0	8.74	7.20	4.95	0.5871
B2 Security ~ infra.	0.11	1	1.0	0.20	0.14	0.0354
B3 Proposed usage	0.11	1.0	1	0.19	0.15	0.0360
B6 Remoteness of area	0.14	5.01	5.18	1	0.31	0.1169
B7 Rollout time	0.20	7.17	6.70	3.22	1	0.2247
						CR = 0.09

F1 *Terrain topography*	**C1**	**C4**	**C5**	**Priority**
C1 Operating cost	1	4.86	0.84	0.4272
C4 Return on investments.	0.21	1	0.21	0.0932
C5 Economic ~ area	1.19	4.86	1	0.4797
				CR = 0.00

F1 *Terrain topography*	**E1**	**E3**	**Priority**
E1 Spectrum	1	1.0	0.5000
E3 Rights of way	1.0	1	0.5000

CR = 0.00

F2 *Climatic conditions*	**A1**	**A2**	**A4**	**A5**	**A6**	**Priority**
A1 Reliability	1	1.57	9.0	5.01	8.74	0.4630
A2 Ease of main.	0.64	1	6.30	3.08	4.68	0.2889
A4 Compatibility	0.11	0.16	1	0.14	1.19	0.0391
A5 Ease of install.	0.20	0.32	6.96	1	6.85	0.1692
A6 Scalability	0.11	0.21	0.84	0.15	1	0.0398

CR = 0.07

F2 *Climatic conditions*	**B6**	**B7**	**Priority**
B6 Remoteness of area	1	0.29	0.2262
B7 Rollout time	3.42	1	0.7738

CR = 0.00

F2 *Climatic conditions*	**C1**	**C5**	**Priority**
C1 Operating cost	1	6.88	0.8433
C5 Economic ~ area	0.15	1	0.1567

CR = 0.00

Table I.2 Pairwise matrices for *Alternatives* with respect to *Criteria*

A1 Reliability	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fiber	1	8.24	3.35	5.73	0.5804
G2 Power line	0.12	1	0.18	0.22	0.0435
G3 Microwave	0.30	5.63	1	3.83	0.2623
G4 Satellite	0.17	4.61	0.26	1	0.1138

CR = 0.09

A2 Ease ~ maintenance	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fiber	1	0.76	0.17	0.27	0.0835
G2 Power line	1.32	1	0.23	0.37	0.1126
G3 Microwave	6.05	4.36	1	1.57	0.4941
G4 Satellite	3.71	2.71	0.64	1	0.3098

CR = 0.01

A3 Remote ~management	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fiber	1	1.41	0.37	0.27	0.1148
G2 Power line	0.71	1	0.26	0.20	0.0822
G3 Microwave	2.71	3.81	1	0.27	0.2482
G4 Satellite	3.66	5.01	3.64	1	0.5547

CR = 0.05

A4 Compatibility	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fiber	1	3.94	0.29	0.41	0.1486
G2 Power line	0.25	1	0.14	0.26	0.0558
G3 Microwave	3.48	6.96	1	4.12	0.5716
G4 Satellite	2.45	3.83	0.24	1	0.2240

CR = 0.07

A5 Ease ~ installation	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fiber	1	3.66	0.41	0.17	0.1264
G2 Power line	0.27	1	0.27	0.17	0.0602
G3 Microwave	2.45	3.66	1	0.23	0.2061
G4 Satellite	5.73	5.80	4.36	1	0.6073
					CR = 0.09

A6 Scalability	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fiber	1	5.85	1.32	4.86	0.4309
G2 Power line	0.17	1	0.18	0.25	0.0543
G3 Microwave	0.76	5.42	1	6.0	0.4011
G4 Satellite	0.21	3.94	0.17	1	0.1173
					CR = 0.09

A7 Bandwidth	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fiber	1	6.18	3.94	8.45	0.6149
G2 Power line	0.16	1	0.21	0.76	0.0639
G3 Microwave	0.25	4.70	1	5.60	0.2571
G4 Satellite	0.12	1.32	0.18	1	0.0641
					CR = 0.06

A8 Flexibility	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fiber	1	3.94	0.71	0.41	0.2037
G2 Power line	0.25	1	0.22	0.13	0.0570
G3 Microwave	1.41	4.56	1	0.71	0.2881
G4 Satellite	2.45	7.94	1.41	1	0.4512
					CR = 0.03

A9 Latency	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fiber	1	1.57	4.09	9.0	0.4725
G2 Power line	0.64	1	3.25	7.54	0.3408
G3 Microwave	0.24	0.31	1	6.42	0.1483
G4 Satellite	0.11	0.13	0.16	1	0.0384
					CR = 0.06

B1 Coverage	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fiber	1	0.64	0.22	0.11	0.0581
G2 Power line	1.57	1	0.32	0.12	0.0813
G3 Microwave	4.61	3.16	1	0.44	0.2614
G4 Satellite	9.0	8.45	2.28	1	0.5993
					CR = 0.04

B2 Security ~ infrastructure	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fiber	1	0.89	3.71	5.58	0.3903
G2 Power line	1.12	1	4.47	5.80	0.4363
G3 Microwave	0.27	0.22	1	1.32	0.0999
G4 Satellite	0.18	0.17	0.76	1	0.0736
					CR = 0.00

B3 *Proposed usage*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fiber	1	1.41	6.18	5.80	0.4832
G2 Power line	0.71	1	4.58	4.56	0.3562
G3 Microwave	0.16	0.22	1	0.64	0.0706
G4 Satellite	0.17	0.22	1.57	1	0.0901
					CR = 0.01

B4 *Availability ~ technicians*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fiber	1	1.32	7.77	5.42	0.4706
G2 Power line	0.76	1	6.05	5.01	0.3801
G3 Microwave	0.13	0.17	1	0.41	0.0533
G4 Satellite	0.18	0.20	2.45	1	0.0961
					CR = 0.02

B5 *Access of ~ infrastructure*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fiber	1	0.71	0.11	0.23	0.0636
G2 Power line	1.41	1	0.17	0.30	0.0896
G3 Microwave	9.0	6.0	1	1.97	0.5589
G4 Satellite	4.41	3.35	0.51	1	0.2880
					CR = 0.04

B6 *Remoteness of area*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fiber	1	0.64	0.16	0.11	0.0521
G2 Power line	1.57	1	0.20	0.12	0.0706
G3 Microwave	6.34	4.88	1	0.51	0.3175
G4 Satellite	9.0	8.45	1.97	1	0.5599
					CR = 0.07

B7 *Rollout time*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fiber	1	1.19	8.45	8.13	0.4830
G2 Power line	0.84	1	6.40	6.24	0.3852
G3 Microwave	0.12	0.16	1	3.60	0.0867
G4 Satellite	0.12	0.16	0.28	1	0.0450
					CR = 0.08

B8 *Parallel infrastructure*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fiber	1	2.06	5.58	7.35	0.5348
G2 Power line	0.49	1	3.44	5.73	0.3112
G3 Microwave	0.18	0.29	1	1.19	0.0877
G4 Satellite	0.14	0.17	0.84	1	0.0664
					CR = 0.01

C1 *Operating cost*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fiber	1	1.11	0.22	0.24	0.0470
G2 Power line	9.0	1	3.81	4.36	0.5929
G3 Microwave	4.45	0.26	1	2.59	0.2260
G4 Satellite	4.24	0.23	0.39	1	0.1341
					CR = 0.06

C2 Funding	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	1.32	0.28	0.24	0.1042
G2 Power line	0.76	1	0.19	0.24	0.0821
G3 Microwave	3.60	5.18	1	2.14	0.4871
G4 Satellite	4.24	4.09	0.47	1	0.3266
					CR = 0.03

C3 *Capital cost*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.20	0.11	0.23	0.0484
G2 Power line	5.05	1	0.47	1.41	0.2429
G3 Microwave	9.0	2.14	1	3.94	0.5373
G4 Satellite	4.36	0.71	0.25	1	0.1713
					CR = 0.01

C4 *Return ~ investment*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.64	0.24	0.27	0.0838
G2 Power line	1.57	1	0.14	1.0	0.1216
G3 Microwave	4.21	7.17	1	4.41	0.6179
G4 Satellite	3.71	1.0	0.23	1	0.1766
					CR = 0.09

C5 *Economic develop ~ area*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.44	3.81	4.41	0.3082
G2 Power line	2.28	1	4.12	5.96	0.5082
G3 Microwave	0.26	0.24	1	2.45	0.1174
G4 Satellite	0.23	0.17	0.41	1	0.0655
					CR = 0.04

D1 *Demand*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	2.28	6.84	7.64	0.5614
G2 Power line	0.44	1	3.31	5.09	0.2751
G3 Microwave	0.15	0.30	1	4.05	0.1144
G4 Satellite	0.13	0.20	0.25	1	0.0490
					CR = 0.07

D2 *Affordability*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.47	0.12	0.12	0.0439
G2 Power line	2.14	1	0.17	0.20	0.0783
G3 Microwave	8.45	5.79	1	3.94	0.5976
G4 Satellite	8.13	5.05	0.25	1	0.2801
					CR = 0.09

D3 *Population density*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.64	0.23	0.13	0.0640
G2 Power line	1.57	1	0.41	0.21	0.1050
G3 Microwave	4.41	2.45	1	0.29	0.2340
G4 Satellite	7.94	4.82	3.44	1	0.5970
					CR = 0.02

D4 *Community ~ interest*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.17	0.49	0.13	0.0482
G2 Power line	5.73	1	7.42	0.28	0.2829
G3 Microwave	2.06	0.13	1	0.11	0.0632
G4 Satellite	7.97	3.56	9.0	1	0.6057
					CR = 0.09

E1 *Spectrum availability*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	1.0	0.13	0.11	0.0511
G2 Power line	1.0	1	0.13	0.13	0.0523
G3 Microwave	7.42	7.42	1	0.27	0.2928
G4 Satellite	8.49	7.97	3.66	1	0.6038
					CR = 0.07

E2 *Licensing constraints*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.43	2.71	5.01	0.2903
G2 Power line	2.34	1	3.46	7.33	0.5201
G3 Microwave	0.37	0.29	1	2.0	0.1263
G4 Satellite	0.20	0.13	0.50	1	0.0633
					CR = 0.01

E3 *Rights of way*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	2.83	7.11	8.49	0.5786
G2 Power line	0.35	1	4.74	7.54	0.3001
G3 Microwave	0.14	0.21	1	1.32	0.0692
G4 Satellite	0.12	0.13	0.76	1	0.0520
					CR = 0.03

F1 *Terrain topography*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.47	0.13	0.11	0.0425
G2 Power line	2.14	1	0.16	0.16	0.0725
G3 Microwave	7.71	6.16	1	0.26	0.2876
G4 Satellite	9.0	6.18	3.83	1	0.5974
					CR = 0.09

F2 *Climatic conditions*	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	1.97	6.85	6.82	0.5334
G2 Power line	0.51	1	4.60	4.76	0.3147
G3 Microwave	0.15	0.22	1	2.45	0.0932
G4 Satellite	0.15	0.21	0.41	1	0.0586
					CR = 0.04

Table I.3 Pairwise matrices for *Criteria* with respect to *Alternatives*

G1 Fibre optic	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**Priority**
A1 Reliability	1	0.84	2.21	2.34	3.56	2.14	0.36	6.40	7.24	0.1392
A2 Ease ~ main.	1.19	1	1.32	6.96	1.97	2.28	0.16	6.96	5.69	0.1513
A3 Remot ~ mng	0.45	0.76	1	3.60	2.06	1.97	2.28	0.16	6.96	0.1024
A4 Compatibility	0.43	0.14	0.28	1	1.86	1.0	0.19	6.40	8.21	0.0708
A5 Ease ~ install	0.28	0.51	0.49	0.54	1	1.57	0.15	2.06	3.56	0.0521
A6 Scalability	0.47	0.44	0.51	1.0	0.64	1	0.11	4.95	6.96	0.0630
A7 Bandwidth	2.74	6.45	4.36	5.14	6.59	9.0	1	8.74	7.97	0.3795
A8 Flexibility	0.16	0.14	0.49	0.16	0.49	0.20	0.11	1	2.45	0.0250
A9 Latency	0.14	0.18	0.13	0.12	0.28	0.14	0.13	0.41	1	0.1658

CR = 0.09

G1 *Fibre optic*	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**Priority**
B1 Coverage	1	2.74	5.44	8.21	7.0	1.0	0.75	7.94	0.2311
B2 Security ~ infra	0.36	1	0.84	2.29	5.14	0.39	0.14	5.96	0.0816
B3 Proposed usage	0.18	1.20	1	5.10	7.17	0.18	0.15	6.30	0.0918
B4 Avail ~ techni.	0.12	0.44	0.20	1	1.32	0.19	0.19	0.84	0.0303
B5 Access ~ infra	0.14	0.19	0.14	0.76	1	0.17	0.13	0.76	0.0234
B6 Remote of area	1.0	2.55	5.44	5.32	5.79	1	0.64	8.21	0.2127
B7 Rollout time	1.33	7.09	6.59	5.14	7.71	1.57	1	6.96	0.3038
B8 Parallel infra.	0.13	0.17	0.16	1.19	1.32	0.12	0.14	1	0.0252

CR = 0.07

G1 *Fibre optic*	**C1**	**C2**	**C3**	**C4**	**C5**	**Priority**
C1 Operating cost	1	6.40	6.34	3.20	7.00	0.5629
C2 Funding	0.16	1	1.57	1.19	5.96	0.1554
C3 Capital cost	0.16	0.64	1	1.32	3.03	0.1127
C4 Return on investments	0.31	0.84	0.76	1	3.66	0.1273
C5 Economic ~ area	0.14	0.17	0.33	0.27	1	0.0417

CR = 0.06

G1 Fibre optic	**D1**	**D2**	**D3**	**D4**	**Priority**
D1 Demand	1	2.89	6.85	5.09	0.5510
D2 Affordability	0.35	1	6.34	4.33	0.3041
D3 Population density	0.15	0.16	1	1.32	0.0713
D4 Community of interest	0.20	0.23	0.76	1	0.0736

CR = 0.06

G1 Fibre optic	**E1**	**E2**	**E3**	**Priority**
E1 Spectrum	1	1.19	4.79	0.4475
E2 Licensing constraints	0.84	1	4.68	0.4518
E3 Rights of way	0.21	0.21	1	0.1007

CR = 0.00

G1 Fibre optic	**F1**	**F2**	**Priority**
F1 Terrain topography	1	8.21	0.8914
F2 Climatic conditions	0.12	1	0.1086

CR = 0.00

G2 Power line	A1	A2	A3	A4	A5	A6	A7	A8	A9	Priority
A1 Reliability	1	0.71	0.76	0.27	0.19	0.23	1.57	0.17	7.09	0.0465
A2 Ease ~ main.	1.41	1	0.71	0.20	0.19	0.20	1.32	0.14	5.33	0.0425
A3 Remot ~ mng	1.32	1.41	1	0.18	0.41	0.16	1.57	0.19	3.66	0.0461
A4 Compatibility	3.66	5.09	5.54	1	1.57	1.19	5.21	4.28	7.17	0.2361
A5 Ease ~ install	5.21	5.38	2.45	0.64	1	0.84	8.21	2.21	6.85	0.1814
A6 Scalability	4.36	4.95	6.40	0.84	1.19	1	8.49	5.01	7.71	0.2493
A7 Bandwidth	0.64	0.76	0.64	0.19	0.12	0.12	1	0.12	4.56	0.0316
A8 Flexibility	6.06	7.09	5.38	0.23	0.45	0.20	8.49	1	3.83	0.1486
A9 Latency	0.14	0.19	0.27	0.14	0.15	0.13	0.22	0.26	1	0.0180

CR = 0.10

G2 Power line	B1	B2	B3	B4	B5	B6	B7	B8	Priority
B1 Coverage	1	1.41	0.25	5.73	0.76	0.84	7.64	0.15	0.0829
B2 Security ~ infra	0.71	1	0.14	1.97	0.49	0.51	7.64	0.21	0.0594
B3 Proposed usage	4.05	6.96	1	5.69	1.32	1.19	6.70	0.18	0.1734
B4 Avail ~ techni.	0.17	0.51	0.18	1	0.15	0.17	3.08	0.14	0.0284
B5 Access ~ infra	1.32	2.06	0.76	6.59	1	0.76	6.32	0.16	0.1026
B6 Remote of area	1.19	1.97	0.84	5.92	1.32	1	4.58	0.19	0.1050
B7 Rollout time	0.13	0.13	0.15	0.32	0.16	0.22	1	0.11	0.0178
B8 Parallel infra.	6.85	4.79	5.57	7.09	6.44	5.29	9.0	1	0.4305

CR = 0.09

G2 Power line	C1	C2	C3	C4	C5	Priority
C1 Operating cost	1	0.16	0.16	0.29	0.36	0.0464
C2 Funding	6.34	1	0.17	1.32	0.64	0.1545
C3 Capital cost	6.40	5.96	1	3.03	3.56	0.5074
C4 Return on investments	3.46	0.76	0.33	1	1.19	0.1444
C5 Economic ~ area	2.74	1.57	0.28	0.84	1	0.1474

CR = 0.07

G2 Power line	D1	D2	D3	D4	Priority
D1 Demand	1	1.32	4.82	4.33	0.4227
D2 Affordability	0.76	1	6.34	5.09	0.4124
D3 Population density	0.21	0.16	1	1.57	0.0885
D4 Community of interest	0.23	0.20	0.64	1	0.0763

CR = 0.03

G2 Power line	E1	E2	E3	Priority
E1 Spectrum	1	0.23	0.11	0.0646
E2 Licensing constraints	4.28	1	0.26	0.2268
E3 Rights of way	9.0	3.81	1	0.7086

CR = 0.04

G2 Power line	F1	F2	Priority
F1 Terrain topography	1	0.24	0.1919
F2 Climatic conditions	4.21	1	0.8081

CR = 0.00

G3 Microwave	A1	A2	A3	A4	A5	A6	A7	A8	A9	Priority
A1 Reliability	1	1.41	2.45	5.54	6.85	6.40	1.32	5.38	0.16	0.1506
A2 Ease ~ main.	0.71	1	2.21	3.66	6.16	4.36	0.51	1.57	0.17	0.0977
A3 Remot ~ mng	0.41	0.45	1	4.28	3.16	4.95	0.51	3.83	0.15	0.0840
A4 Compatibility	0.18	0.27	0.23	1	0.71	1.0	0.20	0.29	0.15	0.0242
A5 Ease ~ install	0.15	0.16	0.32	1.41	1	1.97	0.16	0.34	0.17	0.0285
A6 Scalability	0.16	0.23	0.20	1.0	0.51	1	0.13	0.51	0.20	0.0252
A7 Bandwidth	0.76	1.97	1.97	5.09	6.12	7.71	1	3.08	0.14	0.1313
A8 Flexibility	0.19	0.64	0.26	3.48	2.94	1.97	0.32	1	0.31	0.0550
A9 Latency	6.40	6.05	6.65	6.82	5.79	4.95	6.96	3.20	1	0.4035

CR = 0.09

G3 Microwave	B1	B2	B3	B4	B5	B6	B7	B8	Priority
B1 Coverage	1	4.40	7.0	4.21	5.38	5.69	8.49	5.38	0.4021
B2 Security ~ infra	0.23	1	2.45	1.57	1.0	1.32	8.49	3.20	0.1330
B3 Proposed usage	0.14	0.41	1	0.22	0.18	0.41	1.0	5.01	0.0464
B4 Avail ~ techni.	0.24	0.64	4.53	1	0.76	1.09	1.57	6.59	0.1059
B5 Access ~ infra	0.19	1.0	5.54	1.32	1	3.20	4.90	5.60	0.1557
B6 Remote of area	0.18	0.76	2.45	0.92	0.31	1	5.01	4.70	0.0935
B7 Rollout time	0.12	0.12	1.0	0.64	0.20	0.20	1	2.78	0.0377
B8 Parallel infra.	0.19	0.31	0.20	0.15	0.18	0.21	0.36	1	0.0256

CR = 0.09

G3 Microwave	C1	C2	C3	C4	C5	Priority
C1 Operating cost	1	1.19	6.40	3.20	3.60	0.3475
C2 Funding	0.84	1	6.40	3.96	6.96	0.4040
C3 Capital cost	0.16	0.16	1	0.31	0.30	0.0430
C4 Return on investments	0.31	0.25	3.20	1	0.76	0.1019
C5 Economic ~ area	0.28	0.14	3.35	1.32	1	0.1035

CR = 0.04

G3 Microwave	D1	D2	D3	D4	Priority
D1 Demand	1	6.40	6.40	8.74	0.6725
D2 Affordability	0.16	1	2.14	4.47	0.1675
D3 Population density	0.16	0.47	1	4.68	0.1173
D4 Community of interest	0.11	0.22	0.21	1	0.0427

CR = 0.10

G3 Microwave	E1	E2	E3	Priority
E1 Spectrum	1	3.60	8.74	0.7082
E2 Licensing constraints	0.28	1	3.35	0.2190
E3 Rights of way	0.11	0.30	1	0.0728

CR = 0.01

G3 Microwave	F1	F2	Priority
F1 Terrain topography	1	5.38	0.8433
F2 Climatic conditions	0.19	1	0.1567

CR = 0.00

G4 Satellite	A1	A2	A3	A4	A5	A6	A7	A8	A9	Priority
A1 Reliability	1	0.64	0.16	0.35	0.19	0.13	0.20	0.18	0.13	0.0190
A2 Ease ~ main.	1.57	1	0.71	0.21	0.84	0.24	0.35	0.16	0.13	0.0289
A3 Remot ~ mng	6.40	1.41	1	1.32	1.57	0.30	0.23	0.16	0.18	0.0501
A4 Compatibility	2.89	4.79	0.76	1	1.19	0.19	0.35	0.25	0.15	0.0504
A5 Ease ~ install	5.38	1.19	0.64	0.84	1	0.35	0.20	0.35	0.13	0.0442
A6 Scalability	7.71	4.21	3.35	5.14	2.89	1	1.0	0.41	0.13	0.1181
A7 Bandwidth	5.01	2.89	4.40	2.82	5.01	1.0	1	0.13	0.34	0.1124
A8 Flexibility	5.69	6.16	6.16	3.87	2.89	2.43	7.71	1	0.51	0.2450
A9 Latency	7.97	7.45	5.69	6.59	7.42	7.71	2.91	1.97	1	0.3318

CR = 0.10

G4 Satellite	B1	B2	B3	B4	B5	B6	B7	B8	Priority
B1 Coverage	1	0.11	0.32	0.18	1.0	1.32	0.71	0.14	0.0297
B2 Security ~ infra	9.0	1	5.98	1.57	7.17	7.71	7.09	0.17	0.2301
B3 Proposed usage	3.08	0.17	1	0.84	1.97	5.44	1.0	0.21	0.0743
B4 Avail ~ techni.	5.44	0.63	1.19	1	5.14	4.61	7.71	0.32	0.1539
B5 Access ~ infra	1.0	0.14	0.51	0.19	1	2.34	0.76	0.11	0.0339
B6 Remote of area	0.76	0.13	0.18	0.22	0.43	1	0.19	0.12	0.0220
B7 Rollout time	1.41	0.14	1.0	0.13	1.32	5.32	1	0.20	0.0524
B8 Parallel infra.	7.35	5.96	4.79	3.08	9.0	8.21	5.0	1	0.4037

CR = 0.09

G4 Satellite	C1	C2	C3	C4	C5	Priority
C1 Operating cost	1	0.39	1.19	0.22	0.25	0.0771
C2 Funding	2.55	1	3.35	1.32	3.35	0.3540
C3 Capital cost	0.84	0.30	1	0.22	0.19	0.0636
C4 Return on investments	4.61	0.76	4.53	1	1.41	0.2840
C5 Economic ~ area	3.94	0.30	5.38	0.71	1	0.2212

CR = 0.07

G4 Satellite	D1	D2	D3	D4	Priority
D1 Demand	1	0.27	2.34	2.28	0.2109
D2 Affordability	3.66	1	4.79	4.36	0.5596
D3 Population density	0.43	0.21	1	0.29	0.0777
D4 Community of interest	0.44	0.23	3.46	1	0.1518

CR = 0.09

G4 Satellite	E1	E2	E3	Priority
E1 Spectrum	1	2.45	6.65	0.6022
E2 Licensing constraints	0.41	1	6.59	0.3304
E3 Rights of way	0.15	0.15	1	0.0674

CR = 0.08

G4 Satellite	F1	F2	Priority
F1 Terrain topography	1	0.14	0.1236
F2 Climatic conditions	7.09	1	0.8764

CR = 0.00

Table I.4 Pairwise matrices for *Clusters* with respect to *Clusters*

***A** Technical*	**A**	**B**	**C**	**D**	**G**	**Priority**
A Technical	1	3.08	0.76	3.08	6.65	0.3198
B Infrastructure	0.32	1	0.24	1.0	2.14	0.1035
C Economic	1.32	4.09	1	4.09	9.0	0.4252
D Social	0.32	1.0	0.24	1	2.14	0.1035
G Alternatives	0.15	0.47	0.11	0.47	1	0.0480
						CR = 0.00

***B** Infrastructure*	**A**	**B**	**C**	**D**	**G**	**Priority**
A Technical	1	1.57	0.21	1.97	5.96	0.1599
B Infrastructure	0.64	1	0.14	1.32	3.83	0.1035
C Economic	4.79	7.35	1	9.0	9.0	0.6197
D Social	0.51	0.76	0.11	1	3.0	0.0809
G Alternatives	0.17	0.26	0.11	0.33	1	0.0360
						CR = 0.04

***C** Economic*	**B**	**C**	**G**	**Priority**
B Infrastructure	1	0.64	5.0	0.3599
C Economic	1.57	1	8.0	0.5686
G Alternatives	0.20	0.13	1	0.0715
				CR = 0.00

***D** Social*	**A**	**B**	**C**	**D**	**G**	**Priority**
A Technical	1	1.57	0.64	5.0	6.0	0.2814
B Infrastructure	0.64	1	0.39	3.0	3.48	0.1721
C Economic	1.57	2.59	1	7.77	9.0	0.4412
D Social	0.20	0.33	0.13	1	1.19	0.0570
G Alternatives	0.17	0.29	0.11	0.84	1	0.0483
						CR = 0.02

***E** Regulatory*	**A**	**B**	**C**	**D**	**E**	**G**	**Priority**
A Technical	1	1.41	0.51	3.94	4.53	5.58	0.2374
B Infrastructure	0.71	1	0.39	2.78	3.16	3.87	0.1690
C Economic	1.97	2.59	1	7.35	7.94	9.0	0.4348
D Social	0.25	0.36	0.14	1	1.19	1.41	0.0611
E Regulatory	0.22	0.32	0.13	0.84	1	1.32	0.0539
G Alternatives	0.18	0.26	0.11	0.71	0.76	1	0.0437
							CR = 0.07

***F** Environmental*	**A**	**B**	**C**	**D**	**E**	**G**	**Priority**
A Technical	1	1.32	0.26	1.97	3.22	5.58	0.1673
B Infrastructure	0.76	1	0.19	1.32	2.45	4.36	0.1248
C Economic	3.83	5.14	1	6.70	8.74	9.0	0.5271
D Social	0.51	0.76	0.15	1	1.97	3.22	0.0933
E Regulatory	031	0.41	0.11	0.51	1	1.57	0.0523
G Alternatives	0.18	0.23	0.11	0.31	0.64	1	0.0353
							CR = 0.01

***G** Alternatives*	**A**	**B**	**C**	**D**	**E**	**F**	**Priority**
A Technical	1	0.83	0.34	2.43	3.22	2.94	0.1673
B Infrastructure	1.20	1	0.43	2.94	3.94	3.56	0.1248
C Economic	2.91	2.34	1	7.0	9.0	8.49	0.5271
D Social	0.41	0.34	0.14	1	1.41	1.19	0.0933
E Regulatory	0.31	0.25	0.11	0.71	1	0.84	0.0523
F Environmental	0.34	0.28	0.12	0.84	1.19	1	0.0353
							CR = 0.01

Table I.5 The cluster matrix

Clusters	A	B	C	D	E	F	G
A Technical	0.3198	0.1600	0.0000	0.2814	0.2374	0.1673	0.1628
B Infrastructure	0.1035	0.1035	0.3599	0.1721	0.1690	0.1248	0.1976
C Economic	0.4252	0.6197	0.5686	0.4412	0.4348	0.5271	0.4663
D Social	0.1035	0.0809	0.0000	0.0570	0.0611	0.0933	0.0675
E Regulatory	0.0000	0.0000	0.0000	0.0000	0.0539	0.0523	0.0495
F Environmental	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0563
G Alternatives	0.0480	0.0360	0.0715	0.0483	0.0437	0.0353	0.0000

Appendix J: ANP model's supermatrices

Table J.1 The unweighted supermatrix

		A									B								C					D				E			F		G			
		A1	A2	A3	A4	A5	A6	A7	A8	A9	B1	B2	B3	B4	B5	B6	B7	B8	C1	C2	C3	C4	C5	D1	D2	D3	D4	E1	E2	E3	F1	F2	G1	G2	G3	G4
	A1	0.000	1.000	0.000	0.000	0.000	0.000	0.631	0.000	0.000	0.000	0.815	0.000	0.132	0.000	0.125	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.113	0.463	0.139	0.046	0.151	0.019
	A2	0.000	0.000	1.000	0.569	0.543	0.000	0.000	0.416	0.000	0.000	0.101	0.000	0.719	0.000	0.157	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.768	0.393	0.289	0.151	0.042	0.098	0.029
	A3	0.000	0.000	0.000	0.431	0.000	0.000	0.291	0.000	0.000	0.721	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.102	0.046	0.084	0.050
	A4	0.000	0.000	0.000	0.000	0.457	0.000	0.000	0.091	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.035	0.039	0.071	0.236	0.024	0.050
A	A5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.080	0.000	0.000	0.083	0.000	0.150	0.000	0.527	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.232	0.393	0.169	0.052	0.181	0.028	0.044
	A6	0.000	0.000	0.000	0.000	0.000	0.000	0.078	0.413	0.000	0.000	0.000	0.000	0.000	0.000	0.039	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.543	0.000	0.123	0.000	0.146	0.208	0.000	0.035	0.040	0.063	0.249	0.025	0.118
	A7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.279	0.000	1.000	0.000	0.000	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.457	0.000	0.777	0.000	0.774	0.424	0.000	0.000	0.000	0.380	0.032	0.131	0.112
	A8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.100	0.000	0.000	0.203	0.000	0.032	0.000	0.025	0.149	0.055	0.245
	A9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.096	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.080	0.166	0.000	0.000	0.000	0.017	0.018	0.404	0.332
	B1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.471	0.000	0.168	0.000	0.000	0.000	1.000	0.396	0.155	0.000	0.572	0.708	0.510	0.644	0.000	0.587	0.000	0.231	0.083	0.402	0.030
	B2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.148	0.000	0.000	0.000	0.000	0.000	0.000	0.062	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.035	0.000	0.082	0.059	0.133	0.230
	B3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.163	0.000	0.030	0.000	0.000	0.000	0.000	0.000	0.000	0.056	0.000	1.000	0.265	0.137	0.067	0.298	0.000	0.036	0.000	0.092	0.173	0.046	0.074
B	B4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.038	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.030	0.028	0.106	0.154
	B5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.173	0.000	0.832	0.000	0.000	0.000	0.000	0.123	0.000	0.000	0.000	0.000	0.000	0.000	0.763	0.000	0.000	0.023	0.103	0.156	0.034
	B6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.090	0.155	0.000	0.000	0.000	0.117	0.226	0.213	0.105	0.094	0.022
	B7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.837	0.000	0.065	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.845	0.000	0.073	0.000	0.424	0.057	0.237	0.225	0.774	0.304	0.018	0.038	0.052
	B8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.075	0.000	0.000	0.000	0.000	0.000	0.000	0.363	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.025	0.430	0.026	0.404
	C1	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.838	0.000	0.245	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.310	0.000	1.000	1.000	1.000	0.427	0.873	0.563	0.046	0.348	0.077
	C2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.744	1.000	0.431	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.155	0.154	0.404	0.354
C	C3	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.265	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.127	0.000	0.058	0.000	0.000	0.000	0.000	0.000	0.000	0.113	0.507	0.043	0.064
	C4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.735	0.000	1.000	0.000	0.000	0.000	0.000	0.755	1.000	0.000	0.256	0.000	0.569	0.873	1.000	0.063	1.000	0.000	0.000	0.000	0.093	0.000	0.127	0.144	0.102	0.284
	C5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.162	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.570	0.000	0.000	0.000	0.000	0.480	0.127	0.042	0.147	0.103	0.221
	D1	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.551	0.423	0.672	0.211
D	D2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	0.000	0.000	0.000	0.000	0.304	0.412	0.168	0.560
	D3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	0.071	0.089	0.117	0.078
	D4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.074	0.076	0.043	0.152
	E1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.500	0.000	0.480	0.065	0.708	0.602
E	E2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.424	0.227	0.219	0.330
	E3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.000	0.095	0.709	0.073	0.067
F	F1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.891	0.192	0.843	0.124
	F2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.109	0.808	0.157	0.876
	G1	0.580	0.083	0.115	0.149	0.126	0.431	0.615	0.204	0.473	0.058	0.390	0.483	0.471	0.064	0.052	0.483	0.535	0.047	0.104	0.048	0.084	0.309	0.561	0.044	0.064	0.048	0.051	0.290	0.579	0.043	0.533	0.000	0.000	0.000	0.000
G	G2	0.044	0.113	0.082	0.056	0.060	0.054	0.064	0.057	0.341	0.081	0.436	0.356	0.380	0.090	0.071	0.385	0.311	0.593	0.082	0.243	0.122	0.508	0.275	0.078	0.105	0.283	0.052	0.520	0.300	0.072	0.315	0.000	0.000	0.000	0.000
	G3	0.262	0.494	0.248	0.572	0.206	0.401	0.257	0.288	0.148	0.261	0.100	0.071	0.053	0.559	0.318	0.087	0.088	0.226	0.487	0.537	0.618	0.117	0.114	0.598	0.234	0.063	0.293	0.126	0.070	0.288	0.093	0.000	0.000	0.000	0.000
	G4	0.114	0.310	0.555	0.224	0.607	0.114	0.064	0.451	0.038	0.599	0.074	0.090	0.096	0.288	0.560	0.045	0.066	0.134	0.327	0.171	0.177	0.065	0.049	0.280	0.597	0.606	0.604	0.063	0.052	0.597	0.059	0.000	0.000	0.000	0.000

Table J.2 The weighted supermatrix

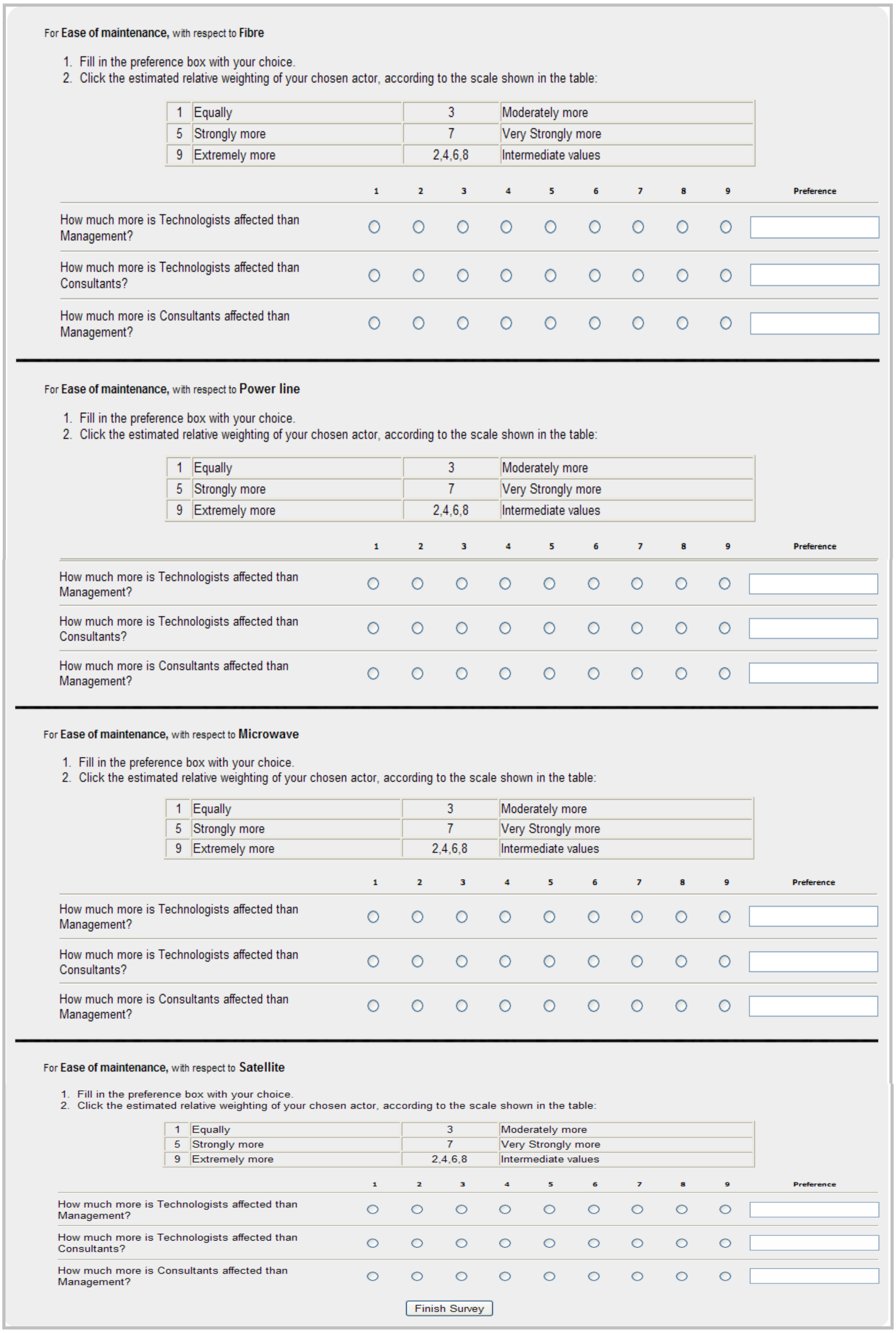
		A									B								C					D				E			F		G			
		A1	A2	A3	A4	A5	A6	A7	A8	A9	B1	B2	B3	B4	B5	B6	B7	B8	C1	C2	C3	C4	C5	D1	D2	D3	D4	E1	E2	E3	F1	F2	G1	G2	G3	G4
A	A1	0.000	0.403	0.000	0.000	0.000	0.000	0.428	0.000	0.000	0.000	0.160	0.000	0.023	0.000	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.019	0.082	0.023	0.008	0.025	0.003
	A2	0.000	0.000	0.869	0.495	0.219	0.000	0.000	0.362	0.000	0.000	0.020	0.000	0.125	0.000	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.194	0.066	0.051	0.025	0.007	0.016	0.005
	A3	0.000	0.000	0.000	0.375	0.000	0.000	0.197	0.000	0.000	0.141	0.000	0.000	0.000	0.534	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.017	0.007	0.014	0.008
	A4	0.000	0.000	0.000	0.000	0.184	0.000	0.000	0.079	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.007	0.012	0.038	0.004	0.008
	A5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.070	0.000	0.000	0.016	0.000	0.026	0.000	0.084	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.059	0.066	0.030	0.008	0.030	0.005	0.007
	A6	0.000	0.000	0.000	0.000	0.000	0.000	0.053	0.359	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.816	0.000	0.000	0.000	0.000	0.000	0.000	0.162	0.000	0.035	0.000	0.037	0.053	0.000	0.006	0.007	0.010	0.041	0.004	0.019
	A7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.055	0.000	0.178	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.136	0.000	0.219	0.000	0.194	0.107	0.000	0.000	0.000	0.062	0.005	0.021	0.018
	A8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.028	0.000	0.000	0.051	0.000	0.005	0.000	0.004	0.024	0.009	0.040
	A9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.042	0.000	0.000	0.000	0.003	0.003	0.066	0.054
B	B1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.346	0.049	0.000	0.023	0.000	0.000	0.000	0.360	0.142	0.028	0.000	0.099	0.170	0.091	0.116	0.000	0.073	0.000	0.046	0.016	0.079	0.006
	B2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.022	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.016	0.012	0.026	0.045
	B3	0.152	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.683	0.000	0.000	0.000	0.018	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.000	0.240	0.046	0.033	0.012	0.054	0.000	0.004	0.000	0.018	0.034	0.009	0.015
	B4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.006	0.021	0.030
	B5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.018	0.000	0.113	0.000	0.000	0.000	0.000	0.044	0.000	0.000	0.000	0.000	0.000	0.000	0.137	0.000	0.000	0.005	0.020	0.031	0.007
	B6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.037	0.000	0.000	0.000	0.015	0.030	0.042	0.021	0.018	0.004
	B7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.094	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.154	0.000	0.013	0.000	0.076	0.010	0.043	0.028	0.102	0.060	0.004	0.007	0.010
	B8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.131	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.085	0.005	0.080
C	C1	0.625	0.536	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.674	0.000	0.520	0.000	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.137	0.000	0.460	0.463	0.463	0.225	0.486	0.262	0.022	0.162	0.036
	C2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.661	0.569	0.245	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.072	0.072	0.188	0.165
	C3	0.000	0.000	0.000	0.000	0.536	0.000	0.000	0.000	0.000	0.201	0.760	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.060	0.000	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.053	0.237	0.020	0.030
	C4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.559	0.000	0.691	0.000	0.000	0.000	0.000	0.616	0.888	0.000	0.227	0.000	0.324	0.408	0.614	0.028	0.614	0.000	0.000	0.000	0.049	0.000	0.059	0.067	0.048	0.132
	C5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.251	0.000	0.000	0.000	0.000	0.253	0.071	0.019	0.069	0.048	0.103
D	D1	0.152	0.000	0.000	0.000	0.000	0.000	0.220	0.000	0.000	0.000	0.000	0.090	0.000	0.000	0.081	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.079	0.057	0.000	0.000	0.000	0.000	0.000	0.000	0.037	0.029	0.045	0.014
	D2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.079	0.065	0.000	0.000	0.000	0.000	0.021	0.028	0.011	0.038
	D3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.093	0.098	0.005	0.006	0.008	0.005
	D4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.005	0.003	0.010
E	E1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.057	0.000	0.026	0.000	0.024	0.003	0.035	0.030
	E2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.057	0.000	0.000	0.021	0.011	0.011	0.016
	E3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.026	0.000	0.005	0.035	0.004	0.003
F	F1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.050	0.011	0.047	0.007
	F2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.045	0.009	0.049
G	G1	0.041	0.005	0.015	0.019	0.008	0.431	0.063	0.027	0.150	0.003	0.017	0.019	0.018	0.008	0.002	0.089	0.025	0.005	0.104	0.005	0.006	0.022	0.029	0.003	0.003	0.003	0.002	0.014	0.027	0.002	0.020	0.000	0.000	0.000	0.000
	G2	0.003	0.007	0.011	0.007	0.004	0.054	0.007	0.007	0.108	0.004	0.019	0.014	0.015	0.011	0.003	0.071	0.015	0.066	0.082	0.027	0.009	0.036	0.014	0.005	0.005	0.019	0.002	0.024	0.014	0.003	0.012	0.000	0.000	0.000	0.000
	G3	0.019	0.030	0.032	0.075	0.012	0.401	0.026	0.038	0.047	0.012	0.004	0.003	0.002	0.067	0.011	0.016	0.004	0.025	0.487	0.060	0.044	0.008	0.006	0.040	0.011	0.004	0.014	0.006	0.003	0.010	0.003	0.000	0.000	0.000	0.000
	G4	0.008	0.019	0.072	0.029	0.037	0.114	0.007	0.059	0.012	0.026	0.003	0.004	0.004	0.035	0.020	0.008	0.003	0.015	0.327	0.019	0.013	0.005	0.003	0.019	0.029	0.041	0.028	0.003	0.002	0.021	0.002	0.000	0.000	0.000	0.000

Table J.3 The limit supermatrix

		A									B								C					D				E			F		G			
		A1	A2	A3	A4	A5	A6	A7	A8	A9	B1	B2	B3	B4	B5	B6	B7	B8	C1	C2	C3	C4	C5	D1	D2	D3	D4	E1	E2	E3	F1	F2	G1	G2	G3	G4
A	A1	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242
	A2	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281	0.0281
	A3	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221	0.0221
	A4	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034
	A5	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036
	A6	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155	0.0155
	A7	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174
	A8	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045
	A9	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106
B	B1	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796	0.0796
	B2	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069
	B3	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165
	B4	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044
	B5	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065
	B6	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044
	B7	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080	0.0080
	B8	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103
C	C1	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753	0.0753
	C2	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594
	C3	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360
	C4	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715	0.1715
	C5	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172	0.0172
D	D1	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174	0.0174
	D2	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055
	D3	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
	D4	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012
E	E1	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067	0.0067
	E2	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032
	E3	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018
F	F1	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071
	F2	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054	0.0054
G	G1	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322
	G2	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259	0.0259
	G3	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013	0.1013
	G4	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642

Appendix K: ANP BOCR model's pairwise surveys and matrices

K.1 Screenshot sample of the pairwise surveys



For **Ease of maintenance,** with respect to **Fibre**

1. Fill in the preference box with your choice.
2. Click the estimated relative weighting of your chosen actor, according to the scale shown in the table:

1	Equally	3	Moderately more
5	Strongly more	7	Very Strongly more
9	Extremely more	2,4,6,8	Intermediate values

	1	2	3	4	5	6	7	8	9	Preference
How much more is Technologists affected than Management?										
How much more is Technologists affected than Consultants?										
How much more is Consultants affected than Management?										

For **Ease of maintenance,** with respect to **Power line**

1. Fill in the preference box with your choice.
2. Click the estimated relative weighting of your chosen actor, according to the scale shown in the table:

1	Equally	3	Moderately more
5	Strongly more	7	Very Strongly more
9	Extremely more	2,4,6,8	Intermediate values

	1	2	3	4	5	6	7	8	9	Preference
How much more is Technologists affected than Management?										
How much more is Technologists affected than Consultants?										
How much more is Consultants affected than Management?										

For **Ease of maintenance,** with respect to **Microwave**

1. Fill in the preference box with your choice.
2. Click the estimated relative weighting of your chosen actor, according to the scale shown in the table:

1	Equally	3	Moderately more
5	Strongly more	7	Very Strongly more
9	Extremely more	2,4,6,8	Intermediate values

	1	2	3	4	5	6	7	8	9	Preference
How much more is Technologists affected than Management?										
How much more is Technologists affected than Consultants?										
How much more is Consultants affected than Management?										

For **Ease of maintenance,** with respect to **Satellite**

1. Fill in the preference box with your choice.
2. Click the estimated relative weighting of your chosen actor, according to the scale shown in the table:

1	Equally	3	Moderately more
5	Strongly more	7	Very Strongly more
9	Extremely more	2,4,6,8	Intermediate values

	1	2	3	4	5	6	7	8	9	Preference
How much more is Technologists affected than Management?										
How much more is Technologists affected than Consultants?										
How much more is Consultants affected than Management?										

Finish Survey

Figure K.1 A screenshot sample of ANP BOCR questionnaire

K.2 Comparison matrices of strategic criteria

Table K 2.1 Comparisons of strategic criteria with respect to goal

Goal	**PW**	**IE**	**QS**	**CB**	**Priority**
Public **W**elfare	1	1.78	1.85	1.94	0.3776
Infra. **E**nhancement	0.56	1	1.15	2.09	0.2553
Quality of **S**ervices	0.54	0.87	1	1.54	0.2166
Company **B**enefits	0.52	0.48	0.65	1	0.1505

CR = 0.01

Table K 2.2 Comparisons of strategic subcriteria with respect to criteria

Public welfare	**CW**	**TD**	**Priority**
Communities **W**ellbeing	1	2.17	0.6845
Telecoms **D**evelopment	0.46	1	0.3155

CR = 0.00

Infra enhancement	**EC**	**UA**	**Priority**
Extending **C**onnectivity	1	3.20	0.7619
Universality of **A**ccess	0.31	1	0.2381

CR = 0.00

Quality of services	**CS**	**NP**	**Priority**
Client **S**atisfaction	1	1.35	0.5745
Network **P**erformance	0.74	1	0.4255

CR = 0.00

Company benefits	**R**	**M**	**Priority**
Revenues	1	0.69	0.4082
Market	1.45	1	0.5918

CR = 0.00

Table K 2.3 Comparisons of strategic clusters

Clusters	**PW**	**IE**	**QS**	**CB**	**Priority**
Public **W**elfare	1	3.00	7.00	7.00	0.5624
Infra. **E**nhancement	0.33	1	6.00	8.00	0.3165
Quality of **S**ervices	0.14	0.1	1	200	0.0722
Company **B**enefits	0.14	0.13	0.50	1	0.0488

CR = 0.07

K.3 Comparison matrices of Benefits subnet

Table K 3.1 Comparisons of Benefits criteria with respect to goal

Goal	**T**	**I**	**S**	**Priority**
Technical	1	1.37	2.02	0.4491
Infrastructure	0.73	1	1.48	0.3288
Social	0.49	0.68	1	0.2221

CR = 0.00

Table K 3.2 Comparisons of Benefits subcriteria with respect to criteria

Technical	**A1**	**A2**	**A3**	**A4**	**A5**	**Priority**
A1	1	1.05	1.89	2.23	1.83	0.2880
A2	0.95	1	1.80	2.12	1.75	0.2740
A3	0.53	0.55	1	1.18	0.97	0.1520
A4	0.45	0.47	0.85	1	0.82	0.1290
A5	0.54	0.57	1.03	1.22	1	0.1570
						CR = 0.00

Infrastructure	**B1**	**B5**	**Priority**
B1	1	5.17	0.8380
B5	0.19	1	0.1620
			CR = 0.00

Social	**D2**	**D4**	**Priority**
D2	1	0.24	0.1940
D4	4.15	1	0.8060
			CR = 0.00

Table K 3.3 Comparisons of Benefits clusters

Clusters	**T**	**I**	**S**	**Priority**
Technical sub.	1	2.00	0.33	0.2385
Infrastructure sub.	0.50	1	0.25	0.1365
Social sub.	3.00	4.00	1	0.6250
				CR = 0.02

K.4 Comparison matrices of decision subnets under Benefits

Table K 4.1 Comparison matrices under *Reliability* subnet

Fibre	**H1**	**H2**	**H3**	**Priority**
H1 Management	1	5.00	3.00	0.6586
H2 Technologists	0.20	1	1.00	0.1562
H3 Consultants	0.33	1.00	1	0.1852
				CR = 0.03

Fibre	**I1**	**I2**	**I3**	**Priority**
I1 Competitors	1	2.00	0.20	0.1864
I2 Clients	0.50	1	0.25	0.1265
I3 Suppliers	5.00	4.00	1	0.6869
				CR = 0.09

Power line	**H1**	**H2**	**H3**	**Priority**
H1 Management	1	0.33	0.20	0.1094
H2 Technologists	3.00	1	0.50	0.3090
H3 Consultants	5.00	2.00	1	0.5815
				CR = 0.00

Power line	**I1**	**I2**	**I3**	**Priority**
I1 Competitors	1	4.00	2.00	0.5584
I2 Clients	0.25	1	0.33	0.1220
I3 Suppliers	0.50	3.00	1	0.3196
				CR = 0.02

Microwave	**H1**	**H2**	**H3**	**Priority**
H1 Management	1	7.00	5.00	0.7306
H2 Technologists	0.14	1	0.33	0.0810
H3 Consultants	0.20	3.00	1	0.1884
				CR = 0.06

Microwave	**I1**	**I2**	**I3**	**Priority**
I1 Competitors	1	4.00	5.00	0.6870
I2 Clients	0.25	1	0.50	0.1265
I3 Suppliers	0.20	2.00	1	0.1865
				CR = 0.09

Satellite	**H1**	**H2**	**H3**	**Priority**
H1 Management	1	0.17	0.25	0.0852
H2 Technologists	6.00	1	3.00	0.6442
H3 Consultants	4.00	0.33	1	0.2706
				CR = 0.05

Satellite	**I1**	**I2**	**I3**	**Priority**
I1 Competitors	1	5.00	3.00	0.6586
I2 Clients	0.20	1	1.00	0.1562
I3 Suppliers	0.33	1.00	1	0.1852
				CR = 0.03

Management	**H2**	**H3**	**Priority**
H2 Technologists	1	0.24	0.1905
H3 Consultants	4.25	1	0.8095
			CR = 0.00

Management	**I1**	**I2**	**I3**	**Priority**
I1 Competitors	1	0.50	3.00	0.3325
I2 Clients	2.00	1	3.00	0.5278
I3 Suppliers	0.33	0.33	1	0.1396
				CR = 0.05

Management	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	0.20	0.25	0.33	0.0787
G2 Power line	5.00	1	0.87	0.33	0.2329
G3 Microwave	4.00	1.15	1	0.50	0.2475
G4 Satellite	3.00	3.00	2.00	1	0.4408
					CR = 0.09

Technologists	**H1**	**H3**	**Priority**
H1 Management	1	5.56	0.8476
H3 Consultants	0.18	1	0.1524
			CR = 0.00

Technologists	**I2**	**I3**	**Priority**
I2 Clients	1	0.23	0.1901
I3 Suppliers	4.26	1	0.8099
			CR = 0.00

Technologists	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	6.00	2.00	5.00	0.5092
G2 Power line	0.17	1	0.17	0.33	0.0573
G3 Microwave	0.50	6.00	1	3.00	0.3115
G4 Satellite	0.20	3.00	0.33	1	0.1220

CR = 0.04

Consultants	**H1**	**H2**	**Priority**
H1 Management	1	6.35	0.8639
H2 Technologists	0.16	1	0.1361

CR = 0.00

Consultants	**I1**	**I3**	**Priority**
I1 Competitors	1	4.00	0.8000
I3 Suppliers	0.25	1	0.2000

CR = 0.00

Consultants	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	7.00	2.00	3.00	0.4723
G2 Power line	0.14	1	0.25	0.20	0.0557
G3 Microwave	0.50	4.00	1	3.00	0.3033
G4 Satellite	0.33	5.00	0.33	1	0.1687

CR = 0.07

Competitors	**I2**	**I3**	**Priority**
I2 Clients	1	7.00	0.8750
I3 Suppliers	0.14	1	0.1250

CR = 0.00

Competitors	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	2.00	2.00	0.50	0.2956
G2 Power line	0.50	1	1.00	1.15	0.1995
G3 Microwave	0.50	1.00	1	0.97	0.2484
G4 Satellite	2.00	0.87	1	1	0.2566

CR = 0.10

Clients	**I1**	**I3**	**Priority**
I1 Competitors	1	0.14	0.1250
I3 Suppliers	7.00	1	0.8750

CR = 0.00

Clients	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	5.00	3.00	2.00	0.4853
G2 Power line	0.20	1	0.33	0.50	0.0833
G3 Microwave	0.33	3.00	1	3.00	0.2750
G4 Satellite	0.50	2.00	0.33	1	0.1564

CR = 0.08

Suppliers	**H1**	**H2**	**H3**	**Priority**
H1 Management	1	7.00	4.00	0.7049
H2 Technologists	0.14	1	0.33	0.0841
H3 Consultants	0.25	3.00	1	0.2109

CR = 0.03

Suppliers	**I1**	**I2**	**Priority**
I1 Competitors	1	0.17	0.1429
I2 Suppliers	6.00	1	0.8571

CR = 0.00

Suppliers	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	3.00	0.87	0.33	0.2155
G2 Power line	0.33	1	0.50	0.50	0.1239
G3 Microwave	1.15	2.00	1	0.33	0.2000
G4 Satellite	3.00	2.00	3.00	1	0.4606

CR = 0.09

Table K 4.2 Comparisons of *Reliability* subnet clusters

Alternatives	**D**	**O**	**Priority**
Decision **ma**kers	1	5.00	0.8333
O. stakeholders	0.20	1	0.1667

CR = 0.00

Decision Makers	A	**D**	**O**	**Priority**
Alternatives	1	0.20	0.33	0.1047
Decision makers	5.00	1	3.00	0.6370
O. **s**takeholders	3.00	0.33	1	0.2583

CR = 0.04

O. stakeholders	A	**D**	**O**	**Priority**
Alternatives	1	0.17	0.25	0.0852
Decision makers	5.99	1	3.00	0.6442
O. stakeholders	4.00	0.33	1	0.2706

CR = 0.05

Table K 4.3 Comparison matrices under *Ease of maintenance* subnet

Fibre	**H1**	**H2**	**H3**	**Priority**
H1 Management	1	7.00	5.00	0.7306
H2 Technologists	0.14	1	0.33	0.0809
H3 Consultants	0.20	3.00	1	0.1883

CR = 0.06

Fibre	**I1**	**I2**	**I3**	**Priority**
I1 Competitors	1	4.00	5.00	0.6795
I2 Clients	0.25	1	0.33	0.1093
I3 Suppliers	0.20	3.00	1	0.2111

CR = 0.10

Power line	**H1**	**H2**	**H3**	**Priority**
H1 Management	1	0.33	0.20	0.1094
H2 Technologists	3.00	1	0.50	0.3090
H3 Consultants	5.00	2.00	1	0.5815
				CR = 0.03

Power line	**I1**	**I2**	**I3**	**Priority**
I1 Competitors	1	4.00	2.00	0.5584
I2 Clients	0.25	1	0.33	0.1220
I3 Suppliers	0.50	3.00	1	0.3196
				CR = 0.02

Microwave	**H1**	**H2**	**H3**	**Priority**
H1 Management	1	0.17	0.25	0.0852
H2 Technologists	6.00	1	3.00	0.6442
H3 Consultants	4.00	0.33	1	0.2706
				CR = 0.05

Microwave	**I1**	**I2**	**I3**	**Priority**
I1 Competitors	1	5.00	3.00	0.6586
I2 Clients	0.20	1	1.00	0.1562
I3 Suppliers	0.33	1.00	1	0.1852
				CR = 0.03

Satellite	**H1**	**H2**	**H3**	**Priority**
H1 Management	1	5.00	3.00	0.6586
H2 Technologists	0.20	1	1.00	0.1561
H3 Consultants	0.33	1.00	1	0.1851
				CR = 0.02

Satellite	**I1**	**I2**	**I3**	**Priority**
I1 Competitors	1	0.46	0.27	0.1860
I2 Clients	0.68	1	0.18	0.1269
I3 Suppliers	3.69	5.41	1	0.6870
				CR = 0.00

Management	**H2**	**H3**	**Priority**
H2 Technologists	1	0.20	0.1666
H3 Consultants	5.00	1	0.8333
			CR = 0.00

Management	**I1**	**I2**	**I3**	**Priority**
I1 Competitors	1	0.50	3.00	0.3325
I2 Clients	2.00	1	3.00	0.5278
I3 Suppliers	0.33	0.33	1	0.1396
				CR = 0.05

Management	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	5.00	2.00	0.25	0.2389
G2 Power line	0.20	1	0.33	0.20	0.0647
G3 Microwave	0.50	3.00	1	0.33	0.1540
G4 Satellite	4.00	5.00	3.00	1	0.5424
					CR = 0.08

Technologists	**H1**	**H3**	**Priority**
H1 Management	1	0.25	0.2000
H3 Consultants	4.00	1	0.8000

CR = 0.00

Technologists	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	5.99	3.00	0.50	0.3114
G2 Power line	0.16	1	0.33	0.16	0.0573
G3 Microwave	0.33	3.00	1	0.20	0.1219
G4 Satellite	2.00	5.99	5.00	1	0.5092

CR = 0.03

Consultants	**H1**	**H2**	**Priority**
H1 Management	1	5.00	0.8333
H2 Technologists	0.20	1	0.1666

CR = 0.00

Consultants	**I1**	**I3**	**Priority**
I1 Competitors	1	4.00	0.8000
I3 Suppliers	0.25	1	0.2000

CR = 0.00

Consultants	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	4.00	0.33	0.50	0.1702
G2 Power line	0.25	1	0.20	0.14	0.0526
G3 Microwave	3.00	5.00	1	0.33	0.2895
G4 Satellite	2.00	7.00	3.00	1	0.4876

CR = 0.09

Competitors	**I2**	**I3**	**Priority**
I2 Clients	1	4.00	0.8000
I3 Suppliers	0.25	1	0.2000

CR = 0.00

Competitors	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	3.00	0.20	0.33	0.1138
G2 Power line	0.33	1	0.16	0.25	0.0592
G3 Microwave	5.00	5.99	1	5.00	0.6120
G4 Satellite	3.00	4.00	0.20	1	0.2147

CR = 0.09

Clients	**I1**	**I3**	**Priority**
I1 Competitors	1	0.14	0.1250
I3 Suppliers	7.00	1	0.8750

CR = 0.00

Clients	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	3.00	3.00	5.00	0.4990
G2 Power line	0.33	1	0.25	2.00	0.1140
G3 Microwave	0.33	4.00	1	7.00	0.3246
G4 Satellite	0.20	0.49	0.14	1	0.0622

CR = 0.08

Suppliers	**H1**	**H2**	**H3**	**Priority**
H1 Management	1	7.00	4.00	0.7049
H2 Technologists	0.14	1	0.33	0.0841
H3 Consultants	0.25	3.00	1	0.2109

CR = 0.03

Suppliers	**I1**	**I2**	**Priority**
I1 Competitors	1	6.00	0.8571
I2 Suppliers	0.16	1	0.1428

CR = 0.00

Suppliers	**G1**	**G2**	**G3**	**G4**	**Priority**
G1 Fibre	1	2.00	0.33	1.15	0.2000
G2 Power line	0.50	1	0.50	0.33	0.1239
G3 Microwave	3.00	2.00	1	3.00	0.4606
G4 Satellite	0.87	3.00	0.33	1	0.2155

CR = 0.09

Table K 4.2 Comparisons of *Ease of maintenance* subnet clusters

Alternatives	**D**	**O**	**Priority**
Decision **ma**kers	1	4.00	0.8000
O. stakeholders	0.25	1	0.2000

CR = 0.00

Decision Makers	A	**D**	**O**	**Priority**
Alternatives	1	0.20	0.33	0.1047
Decision makers	5.00	1	3.00	0.6370
O. stakeholders	3.00	0.33	1	0.2583

CR = 0.04

O. stakeholders	A	**D**	**O**	**Priority**
Alternatives	1	0.16	0.25	0.0852
Decision makers	6.00	1	3.00	0.6442
O. **s**takeholders	4.00	0.33	1	0.2706

CR = 0.05

Appendix L: Supermatrices of the ANP BOCR model

L.1 Opportunities subnet supermatrices

Table L.1 Unweighted/ weighted supermatrix under Opportunities subnet

	Goal	A	B	C	A4	A6	A8	B1	B3	C4	C5
Max~ing Opportunities	0	0	0	0	0	0	0	0	0	0	0
A Technical	0.3535	0	0	0	0	0	0	0	0	0	0
B Infrastructure	0.3125	0	0	0	0	0	0	0	0	0	0
C Economic	0.3340	0	0	0	0	0	0	0	0	0	0
A4 Compatibility	0	0.3990	0	0	0	0	0	0	0	0	0
A6 Scalability	0	0.3860	0	0	0	0	0	0	0	0	0
A8 Flexibility	0	0.2150	0	0	0	0	0	0	0	0	0
B1 Coverage range	0	0	0.2500	0	0	0	0	0	0	0	0
B3 Usage diversity	0	0	0.7500	0	0	0	0	0	0	0	0
C4 Return ~ investment	0	0	0	0.3105	0	0	0	0	0	0	0
C5 Econ. development	0	0	0	0.6895	0	0	0	0	0	0	0

Table L.2 Limit supermatrix under Opportunities subnet

	Goal	A	B	C	A4	A6	A8	B1	B3	C2	C5
Max~ing Opportunities	0	0	0	0	0	0	0	0	0	0	0
A Technical	0.1768	0	0	0	0	0	0	0	0	0	0
B Infrastructure	0.1563	0	0	0	0	0	0	0	0	0	0
C Economic	0.1670	0	0	0	0	0	0	0	0	0	0
A4 Compatibility	0.0705	0.3990	0	0	0	0	0	0	0	0	0
A6 Scalability	0.0682	0.3860	0	0	0	0	0	0	0	0	0
A8 Flexibility	0.0380	0.2150	0	0	0	0	0	0	0	0	0
B1 Coverage range	0.0391	0	0.2500	0	0	0	0	0	0	0	0
B3 Usage diversity	0.1172	0	0.7500	0	0	0	0	0	0	0	0
C2 Return ~ investment	0.0519	0	0	0.3105	0	0	0	0	0	0	0
C5 Econ. development	0.1152	0	0	0.6895	0	0	0	0	0	0	0

L.2 Costs subnet supermatrices

Table L.3 Unweighted/ weighted supermatrix under Costs subnet

	Goal	A	B	C	E	A3	A7	B6	B7	B8	C1	C2	C3	E1	E2	E3
Minimising Costs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A Technical	0.2410	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B Infrastructure	0.2644	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C Economic	0.2882	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E Regulatory	0.2064	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A3 Remote ~ mng	0	0.5005	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A7 Bandwidth	0	0.4995	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B6 Remote ~ area	0	0	0.4568	0	0	0	0	0	0	0	0	0	0	0	0	0
B7 Rollout time	0	0	0.0890	0	0	0	0	0	0	0	0	0	0	0	0	0
B8 Parallel infra.	0	0	0.4542	0	0	0	0	0	0	0	0	0	0	0	0	0
C1 Operating cost	0	0	0	0.4260	0	0	0	0	0	0	0	0	0	0	0	0
C2 Funding	0	0	0	0.4223	0	0	0	0	0	0	0	0	0	0	0	0
C3 Capital cost	0	0	0	0.1517	0	0	0	0	0	0	0	0	0	0	0	0
E1 Spectrum	0	0	0	0	0.5968	0	0	0	0	0	0	0	0	0	0	0
E2 Licensing	0	0	0	0	0.2027	0	0	0	0	0	0	0	0	0	0	0
E3 Rights of way	0	0	0	0	0.2005	0	0	0	0	0	0	0	0	0	0	0

Table L.4 Limit supermatrix under Costs subnet

	Goal	A	B	C	E	A3	A7	B6	B7	B8	C1	C2	C3	E1	E2	E3
Minimising Costs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A Technical	0.1205	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B Infrastructure	0.1322	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C Economic	0.1441	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E Regulatory	0.1032	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A3 Remote ~ mng	0.0603	0.5005	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A7 Bandwidth	0.0602	0.4995	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B6 Remote ~ area	0.0604	0	0.4568	0	0	0	0	0	0	0	0	0	0	0	0	0
B7 Rollout time	0.0118	0	0.0890	0	0	0	0	0	0	0	0	0	0	0	0	0
B8 Parallel infra.	0.0601	0	0.4542	0	0	0	0	0	0	0	0	0	0	0	0	0
C1 Operating cost	0.0614	0	0	0.4260	0	0	0	0	0	0	0	0	0	0	0	0
C2 Funding	0.0609	0	0	0.4223	0	0	0	0	0	0	0	0	0	0	0	0
C3 Capital cost	0.0219	0	0	0.1517	0	0	0	0	0	0	0	0	0	0	0	0
E1 Spectrum	0.0616	0	0	0	0.5968	0	0	0	0	0	0	0	0	0	0	0
E2 Licensing	0.0209	0	0	0	0.2027	0	0	0	0	0	0	0	0	0	0	0
E3 Rights of way	0.0207	0	0	0	0.2005	0	0	0	0	0	0	0	0	0	0	0

L.3 Risks subnet supermatrices

Table L.5 Unweighted/ weighted supermatrix under Risks subnet

	Goal	A	B	C	D	F	A1	A9	B2	B8	C2	C4	D1	D2	D3	F1	F2
Min~ing Risks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A Technical	0.1915	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B Infrastructure	0.1544	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C Economic	0.2161	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D Social	0.2878	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F Environmental	0.1502	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A1 Reliability	0	0.6612	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A9 Latency	0	0.3388	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B2 Sec.~ infra	0	0	0.7995	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B8 Parallel infra.	0	0	0.2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C2 Funding	0	0	0	0.331	0	0	0	0	0	0	0	0	0	0	0	0	0
C4 Return ~invest	0	0	0	0.669	0	0	0	0	0	0	0	0	0	0	0	0	0
D1 Demand	0	0	0	0	0.4315	0	0	0	0	0	0	0	0	0	0	0	0
D2 Affordability	0	0	0	0	0.1429	0	0	0	0	0	0	0	0	0	0	0	0
D3 Pop ~ density	0	0	0	0	0.4255	0	0	0	0	0	0	0	0	0	0	0	0
F1 Climatic cond.	0	0	0	0	0	0.85	0	0	0	0	0	0	0	0	0	0	0
F2 Topography	0	0	0	0	0	0.15	0	0	0	0	0	0	0	0	0	0	0

Table L.6 Limit supermatrix under Risks subnet

	Goal	A	B	C	D	F	A1	A9	B2	B8	C2	C4	D1	D2	D3	F1	F2
Min~ing Risks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A Technical	0.0958	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B Infrastructure	0.0772	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C Economic	0.1081	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D Social	0.1439	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F Environmental	0.0751	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A1 Reliability	0.0633	0.6612	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A9 Latency	0.0324	0.3388	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B2 Sec.~ infra	0.0617	0	0.7995	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B8 Parallel infra.	0.0155	0	0.2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C2 Funding	0.0358	0	0	0.331	0	0	0	0	0	0	0	0	0	0	0	0	0
C4 Return ~invest	0.0723	0	0	0.669	0	0	0	0	0	0	0	0	0	0	0	0	0
D1 Demand	0.0621	0	0	0	0.4315	0	0	0	0	0	0	0	0	0	0	0	0
D2 Affordability	0.0206	0	0	0	0.1429	0	0	0	0	0	0	0	0	0	0	0	0
D3 Pop ~ density	0.0612	0	0	0	0.4255	0	0	0	0	0	0	0	0	0	0	0	0
F1 Climatic cond.	0.0638	0	0	0	0	0.85	0	0	0	0	0	0	0	0	0	0	0
F2 Topography	0.0113	0	0	0	0	0.15	0	0	0	0	0	0	0	0	0	0	0

Appendix M: The supermatrices of the case study's ANP model

Table M.1 The unweighted supermatrix

		A									B								C					D				E			F		G		
		A1	A2	A3	A4	A5	A6	A7	A8	A9	B1	B2	B3	B4	B5	B6	B7	B8	C1	C2	C3	C4	C5	D1	D2	D3	D4	E1	E2	E3	F1	F2	G1	G2	G3
A	A1	0.000	1.000	0.349	0.217	0.000	0.634	0.297	0.166	0.000	0.000	0.837	0.000	0.120	0.000	0.102	0.000	0.161	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.105	0.344	0.203	0.153	0.147
	A2	0.000	0.000	0.545	0.181	0.444	0.000	0.000	0.473	0.000	0.000	0.000	0.000	0.656	0.000	0.260	0.000	0.839	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.512	0.553	0.042	0.088	0.084
	A3	0.673	0.000	0.000	0.315	0.000	0.000	0.070	0.000	0.000	0.858	0.163	0.650	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.050	0.109	0.150
	A4	0.000	0.000	0.000	0.000	0.332	0.366	0.292	0.066	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.061	0.073	0.039
	A5	0.000	0.000	0.106	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.224	0.766	0.638	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.348	0.104	0.012	0.088	0.033
	A6	0.327	0.000	0.000	0.132	0.224	0.000	0.249	0.295	0.000	0.142	0.000	0.000	0.000	0.157	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.138	0.000	0.000	0.000	0.000	0.082	0.017	0.050
	A7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.232	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	1.000	0.000	1.000	0.000	0.862	0.000	0.000	0.000	0.000	0.347	0.173	0.136
	A8	0.000	0.000	0.000	0.155	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.077	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.036	0.000	0.049	0.081	0.055
	A9	0.000	0.000	0.000	0.000	0.000	0.000	0.093	0.000	0.000	0.000	0.000	0.117	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.153	0.218	0.306
B	B1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.478	0.000	0.000	0.000	0.000	0.000	1.000	0.604	1.000	0.000	0.785	0.837	1.000	0.000	0.000	0.688	0.857	0.226	0.246	0.030
	B2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.124	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.086	0.092	0.237
	B3	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.327	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.070	0.000	0.000	0.215	0.000	0.000	0.000	0.000	0.000	0.000	0.096	0.103	0.095
	B4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.031	0.057	0.136
	B5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.224	1.000	0.805	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.021	0.079	0.039
	B6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.163	0.000	0.000	0.000	0.000	0.000	0.205	0.268	0.023
	B7	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.673	0.000	0.071	0.000	0.195	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	0.068	0.143	0.305	0.038	0.045
	B8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.053	0.000	0.000	0.000	0.000	1.000	0.000	0.326	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.244	0.000	0.028	0.117	0.395
C	C1	1.000	1.000	0.826	0.634	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.871	0.000	0.132	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.157	0.000	1.000	1.000	0.000	0.881	0.843	0.587	0.352	0.399
	C2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.744	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.337	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.170	0.240	0.356
	C3	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.792	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.119	0.157	0.106	0.047	0.068
	C4	0.000	0.000	0.174	0.366	0.000	0.000	0.000	0.256	0.000	0.208	0.000	0.000	0.000	0.000	0.000	0.000	0.089	1.000	0.000	1.000	0.000	0.663	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.093	0.254	0.071
	C5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.129	0.000	0.779	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.843	0.000	0.000	0.000	0.000	0.000	0.000	0.043	0.108	0.106
D	D1	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.593	0.680	0.220
	D2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.276	0.156	0.586
	D3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.068	0.118	0.077
	D4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.063	0.046	0.118
E	E1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.447	0.695	0.640
	E2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.452	0.226	0.298
	E3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.101	0.079	0.061
F	F1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.897	0.834	0.124
	F2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.103	0.166	0.876
G	G1	0.767	0.653	0.591	0.569	0.073	0.710	0.793	0.093	0.715	0.047	0.727	0.733	0.076	0.068	0.048	0.762	0.057	0.601	0.342	0.256	0.053	0.125	0.321	0.627	0.080	0.146	0.096	0.106	0.297	0.062	0.221	0.000	0.000	0.000
	G2	0.168	0.264	0.309	0.348	0.213	0.213	0.148	0.186	0.221	0.174	0.212	0.203	0.685	0.193	0.168	0.191	0.194	0.306	0.293	0.068	0.349	0.142	0.571	0.284	0.151	0.240	0.762	0.106	0.568	0.175	0.068	0.000	0.000	0.000
	G3	0.065	0.083	0.100	0.083	0.714	0.077	0.059	0.721	0.064	0.779	0.061	0.064	0.239	0.739	0.784	0.047	0.748	0.093	0.365	0.676	0.598	0.733	0.108	0.089	0.769	0.614	0.142	0.788	0.134	0.763	0.711	0.000	0.000	0.000

Table M.2 The weighted supermatrix

		A									B								C					D				E			F		G		
		A1	A2	A3	A4	A5	A6	A7	A8	A9	B1	B2	B3	B4	B5	B6	B7	B8	C1	C2	C3	C4	C5	D1	D2	D3	D4	E1	E2	E3	F1	F2	G1	G2	G3
A	A1	0.000	0.383	0.134	0.083	0.000	0.393	0.184	0.064	0.000	0.000	0.570	0.000	0.051	0.000	0.026	0.000	0.068	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.033	0.125	0.046	0.035	0.033
	A2	0.000	0.000	0.208	0.069	0.099	0.000	0.000	0.181	0.000	0.000	0.000	0.000	0.277	0.000	0.067	0.000	0.355	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.161	0.201	0.010	0.020	0.019
	A3	0.107	0.000	0.000	0.121	0.000	0.000	0.043	0.000	0.000	0.363	0.111	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.025	0.034
	A4	0.000	0.000	0.000	0.000	0.074	0.227	0.181	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.585	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.017	0.009
	A5	0.000	0.000	0.041	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.095	0.640	0.164	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.429	0.109	0.038	0.003	0.020	0.008
	A6	0.052	0.000	0.000	0.051	0.050	0.000	0.154	0.113	0.000	0.060	0.000	0.000	0.000	0.131	0.000	0.000	0.000	0.000	0.000	0.397	0.000	0.000	0.000	0.000	0.000	0.000	0.023	0.000	0.000	0.000	0.000	0.019	0.004	0.011
	A7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.071	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000	0.000	0.000	0.137	0.000	0.090	0.000	0.145	0.000	0.000	0.000	0.000	0.079	0.039	0.031
	A8	0.000	0.000	0.000	0.059	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.064	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.011	0.019	0.013
	A9	0.000	0.000	0.000	0.000	0.000	0.000	0.057	0.000	0.000	0.000	0.000	0.036	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.035	0.050	0.070
B	B1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.276	0.000	0.000	0.110	0.000	0.000	0.000	0.000	0.000	0.185	0.321	0.148	0.000	0.077	0.095	0.177	0.000	0.000	0.261	0.376	0.039	0.042	0.005
	B2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.016	0.041
	B3	0.295	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.124	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.037	0.000	0.000	0.021	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.018	0.016
	B4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.010	0.023
	B5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.052	0.819	0.305	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.013	0.007
	B6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.018	0.000	0.000	0.000	0.000	0.000	0.035	0.046	0.004
	B7	0.000	0.000	0.000	0.000	0.415	0.000	0.000	0.000	0.000	0.379	0.000	0.000	0.255	0.000	0.016	0.000	0.074	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.371	0.451	0.026	0.063	0.052	0.007	0.008
	B8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.000	0.000	0.000	0.000	0.321	0.000	0.173	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.092	0.000	0.005	0.020	0.068
C	C1	0.159	0.383	0.316	0.242	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.114	0.000	0.060	0.000	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.185	0.387	0.000	0.075	0.083	0.027	0.016	0.018
	C2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.285	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.125	0.121	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.011	0.016
	C3	0.000	0.000	0.000	0.000	0.224	0.000	0.000	0.000	0.000	0.091	0.184	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.015	0.005	0.002	0.003
	C4	0.000	0.000	0.067	0.140	0.000	0.000	0.000	0.098	0.000	0.024	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.320	0.000	0.217	0.000	0.239	0.067	0.093	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.012	0.003
	C5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.089	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.037	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.005	0.005
D	D1	0.289	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.356	0.000	0.000	0.297	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.339	0.000	0.000	0.000	0.000	0.000	0.000	0.178	0.204	0.066
	D2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.392	0.000	0.000	0.000	0.000	0.000	0.083	0.047	0.176
	D3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.035	0.023
	D4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.653	0.000	0.000	0.000	0.000	0.000	0.422	0.000	0.000	0.000	0.000	0.019	0.014	0.035
E	E1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.143	0.000	0.000	0.000	0.063	0.098	0.090
	E2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.064	0.032	0.042
	E3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.096	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.135	0.000	0.014	0.011	0.009
F	F1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.102	0.095	0.014
	F2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.019	0.099
G	G1	0.075	0.153	0.139	0.134	0.010	0.270	0.301	0.022	0.715	0.004	0.098	0.045	0.006	0.011	0.002	0.138	0.005	0.057	0.048	0.017	0.002	0.013	0.208	0.568	0.034	0.072	0.005	0.010	0.036	0.005	0.022	0.000	0.000	0.000
	G2	0.016	0.062	0.072	0.082	0.029	0.081	0.056	0.044	0.221	0.015	0.029	0.012	0.057	0.032	0.009	0.034	0.016	0.029	0.041	0.004	0.013	0.015	0.370	0.258	0.065	0.119	0.036	0.010	0.068	0.015	0.007	0.000	0.000	0.000
	G3	0.006	0.020	0.024	0.019	0.098	0.029	0.022	0.169	0.064	0.065	0.008	0.004	0.020	0.122	0.040	0.009	0.063	0.009	0.051	0.044	0.022	0.079	0.070	0.080	0.329	0.304	0.007	0.078	0.016	0.066	0.071	0.000	0.000	0.000

Table M.3 The limit supermatrix

		A									B								C					D				E			F		G		
		A1	A2	A3	A4	A5	A6	A7	A8	A9	B1	B2	B3	B4	B5	B6	B7	B8	C1	C2	C3	C4	C5	D1	D2	D3	D4	E1	E2	E3	F1	F2	G1	G2	G3
A	A1	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052
	A2	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
	A3	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038
	A4	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053
	A5	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037
	A6	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
	A7	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
	A8	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
	A9	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
B	B1	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044
	B2	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	B3	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
	B4	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
	B5	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043
	B6	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
	B7	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
	B8	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
C	C1	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059
	C2	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
	C3	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
	C4	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043
	C5	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
D	D1	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059
	D2	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
	D3	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	D4	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
E	E1	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018
	E2	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
	E3	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
F	F1	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
	F2	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
G	G1	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096
	G2	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063
	G3	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046

Appendix N: Case study data

N.1 Survey questionnaire

This survey questionnaire was addressed to several relevant people from the Libya's sole telecoms infrastructure provider "GPTC". It includes several questions covering various facts related to data required by this study. It was sent to a number of personnel involved in the planning of rural telecommunications and also several relevant people attached to GPTC's owned telecoms providers. The aim is to obtain information about the planning and design phase of rural telecommunication infrastructure within a Libyan context.

The questions that were asked are given below:

1. What is meant by rural?
2. Where are rural areas?
3. What is your definition of rural telecommunications?
4. What is the composition of the planning/design team within your area, in terms of their background and expertise?
5. What benefits are expected from a rural telecommunications infrastructure?
6. Who or what section determines which area in particular will receive priority for infrastructure development and what are the driving factors for such choice?
7. What decision making tools or methodologies are available for the selection of rural telecommunications infrastructure?
8. In the planning/design of a particular rural telecommunications infrastructure what consideration is given to the following aspects:

Technological	Economic	Political
Regulatory	Social	Environmental

9. What kind of consultation takes place and with whom, during the planning and design phase of rural telecommunication infrastructure?
10. What mechanisms are there to monitor the success or failure of the newly deployed telecommunication infrastructure?

N.2 Overview of Libya's telecommunications infrastructure

Libya has considerable network and transmission equipment compared to its population: nearly 180 telephone exchanges (main suppliers: Alcatel, Siemens, Ericsson), 14 earth stations providing the national connections via the Arabsat satellite (the Domsat network), international connections and a VSAT network. There is nearly 10,000 km of microwave systems and border-to-border connections, linking the Mediterranean coast from the Tunisian border to Egypt. In addition, submarine cables are extended from Tripoli to Marseilles - France, and Catania - Italy, providing voice and data channels between Libya and Western Europe. There is also more than 30,000 km of UHF radio bands, a 6500 km network of coaxial cables backing up the microwave radio relay system and connecting 107 cities (main suppliers: Pirelli, SIRTI, CEAT and Telettra) (ANIMA, 2009).

The mobile cellular sub-sector system became operational in 1996 and introduced a second GSM network in 2004. This addition has sent the market penetration to one of the highest in Africa within only few years. Third-generation mobile services have been launched and massive investments are being made into a next-generation national fibre optic backbone network (NGN), the expansion of ADSL and WiMAX broadband services, and new international fibre connections (BuddeComm, 2009).

In 2005, the government has passed a law creating the General Authority for Information and Telecommunications (GAIT), which oversees GPTC and its subsidiaries/affiliate companies. The long-standing state-owned General Post and Telecommunications Company (GPTC) was established in 1984 as one of the leading companies in Libya. It currently owns the country's two main mobile telephony operators: Al-Madar Telecom Company (MTC) and Libyana Mobile Phone (LMP). The latter was created in 2004 and it is the second state-owned subsidiary. Libyana's area of coverage will be limited initially to Tripoli, Benghazi and Sabha and has recently signed a contract with two Chinese companies: ZTE (to provide 1.5 million lines) and Huawei Technologies (to provide another million lines). In September 2004, Alcatel and Ericsson obtained a $100 million contract for the supply and installation of a 3G mobile phone network (one million lines each), the first network of this type in Africa. In December 2005 the Swedish firm Ericsson signed a $58 million contract to provide al-Madar with another million lines (ANIMA, 2009).

The Thuraya Company, another subsidiary of GPTC with headquarters in Dubai, offers satellite telecommunication services to mobile users. Libya will be finalizing plans for the Pan African telecommunications satellite RASCOM covering 44 countries, construction of which has been awarded to Alcatel. Plans for a monitoring satellite for the land environment are also under study.

Libya is connected to the Internet by an STM1 link (155Mbps) via an underwater fibre cable between Libya and Italy. The sole supplier of internet access is Libya Telecom & Technology (LTT), a subsidiary of GPTC, but there are now several new providers. A huge number of cyber cafes provide internet access throughout the country and ADSL has also been introduced as well as mobile broadband. Web content development is launched and businesses are starting to embrace the new medium, particularly with the use of mail.

In July 2004, GPTC issued tenders for the installation of next-generation backbone and switching networks, this brought 3 million new lines into service by the end of 2005. GPTC is considering acquiring VSAT and VoIP capabilities in the near future. In September 2004, France's Alcatel and Finland's Nokia won a $244 million contract to expand Libya's nationwide mobile network by 2.5 million new lines, using EvoliumTM mobile radio access and a core network solution to serve GSM/EDGE and 3G users. Nokia's share of the contract applies to the area from Tripoli to the Western mountains, while Alcatel's covers Libya's eastern and southern regions (ANIMA, 2009).

Although there are many problems with maintenance of equipment in Libya, for instance, digitisation has begun only lately, some equipment is in disrepair or out of order, and the rate of penetration in fixed telephony is less than 10 percent. Despite these problems and having a state monopoly form for the provision of posts and telecommunications services, Libya's telecoms network is superior to those in most other African countries. GPTC investments into telecommunications infrastructure over the next 10 years up to 2020 are totalling $10 billion. The procurement for the supply of telephone exchanges for 1.5 million fixed lines (including 500,000 in broadband) and 7000 km of optical fibre network was launched at the end of 2004 (http://www.gcd.ly/Projects.aspx).

N.3 GPTC's existing network infrastructure

GPTC's main aim is to develop the telecommunications infrastructure and boost the level of postal services throughout the country. It oversees postal services, satellite telecommunications, mobile telephony (through its subsidiaries: Al Madar and Libyana), fixed telephony and other associated services. Its other subsidiary, the Libyan Telecom & Technology Company (LTT) is the sole internet service provider (ISP). It operates and maintains wire as well as wireless telecommunications systems and postal centres internally and secures their connectivity with the world. It also acts as a consultant for state-owned companies, supervising big projects such as the Great Man-Made River (GMMR) and municipal initiatives. It owns and regulates the country's telecoms infrastructure including the communication systems described below. It should be noted that it is beyond the scope of this study to engage into a detailed evaluation of such systems, rather the aim is to only highlight the existing transmission systems that could provide connectivity to remote rural areas. The country is served by different systems that include fibre optic cables, microwaves, and satellites. Coaxial cable is also extended to numerous costal and interior points but currently is being obsolete in many different routes. Table N.1 illustrates the high level network architecture numbers (GPTC, 2009).

Table N.1 High-level network architecture numbers

System	Number	Remarks
Microwave	> 400 stations	▪ Covers all over the country.
Satellite	2 Earth Stations 13 Earth Stations	▪ For international use, located in Tripoli and Surt. ▪ For national use, located in around the country.
Fibre	> 4000 km of long-haul fibre installed	▪ This is for the coastal route and links to Sabha only. ▪ Each city has fibre rings that average 1000 km. ▪ Substantial expansion of 8000 km is planned.

An overview of the systems presented in the table above is given below.

N.3.1 Microwave network

The radio network in Libya consists of digital and analogue systems as well as troposcater units to relay signals. The microwave network used for voice and data circuits along the coast and some southern parts of the country has been mostly upgraded from the old technologies and now uses digital microwave equipment at a Synchronous Transfer Mode (STM-1) rate. The national microwave system is built on a combination of three systems; Siemens network and NEC (Analogue & Digital) networks.

Siemens has the largest installed base in the coastal region. The span stretches across the coastline and some distances down into the desert. There are long stretches of active repeater stations where no drop-offs (add-drop-multiplex capability) exist. All microwave add-drop locations are manned sites while Mid-hop repeater sites are unmanned. *NEC* installed 'NEC 5000' units (or in the latter phases of installation) that carry a large amount of traffic. Also, a small route known as route 5 in the microwave layout was awarded recently to serve the southern route from Tripoli towards Tunisia.

The main microwave route along the coast is mirrored by a fibre route. The microwave and fibre routes are used simultaneously for back routing, alarm traffic, and operational information. The microwave systems operate at around 2.4 GHz or higher and stretch from coast to coast and deep into the south of the country. The actual frequency depends on the length and number of hops as well as interference between sites. The capacity of the units varies from an E3 to an NxSTM-1. Because of the combination of desert and coastal terrain, there were some issues of fading and bit errors on some transmission lines in the microwave network infrastructure. Some segments of the microwave networks in the southern routes consist of old analogue equipment and are currently out of service. To overcome these shortcomings and allow for simple interconnections into customers within these regions, GPTC is planning to install digital microwave routes down into Sabha region to replace the outdated ones. Figure N.1 shows the major hub sites along the microwave network.

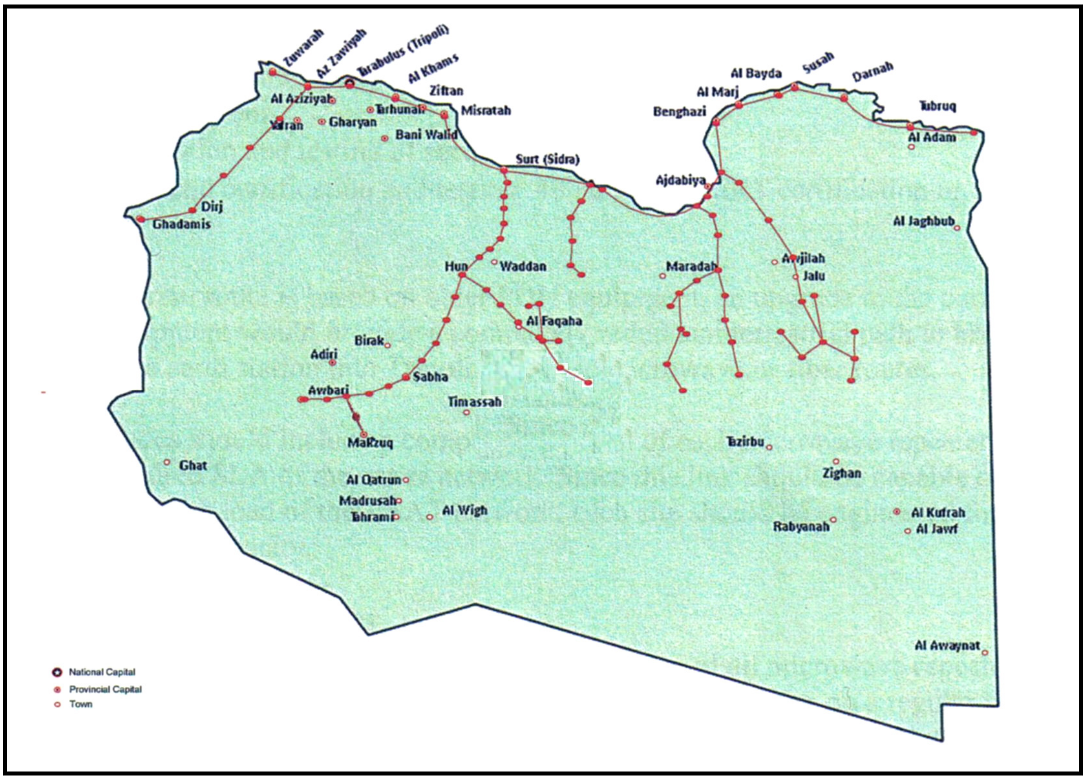


Figure N.1 GPTC Microwave network
(Source: GPTC, 2009)

N.3.2 Satellite network

The GPTC satellite network consists of two main earth stations (one for domestic and one for international) and several remote very small aperture terminals (VSAT) units. The domestic satellite system with 14 earth stations installed throughout the country was constructed to serve areas not fully integrated into the ground-based networks. There are two primary international satellite hub (ground- station complex) located in Souk al-Khamis, near Tripoli and Surt (about 500 km east of Tripoli). GPTC leases a substantial amount of transponder space from the International Telecommunications Satellite (INTELSAT) organisation and has business involvement with Arabsat satellite organisation and Regional African Satellite Communications Organisation (RASCOM). In Arabsat, it is a key member and maintains 11.28% capital ownership and participation. While in RASCOM it is a major signatory along with other African countries. The connectivity of GPTC satellite network is established via multiple transmission systems as demonstrated in Figure N.2.

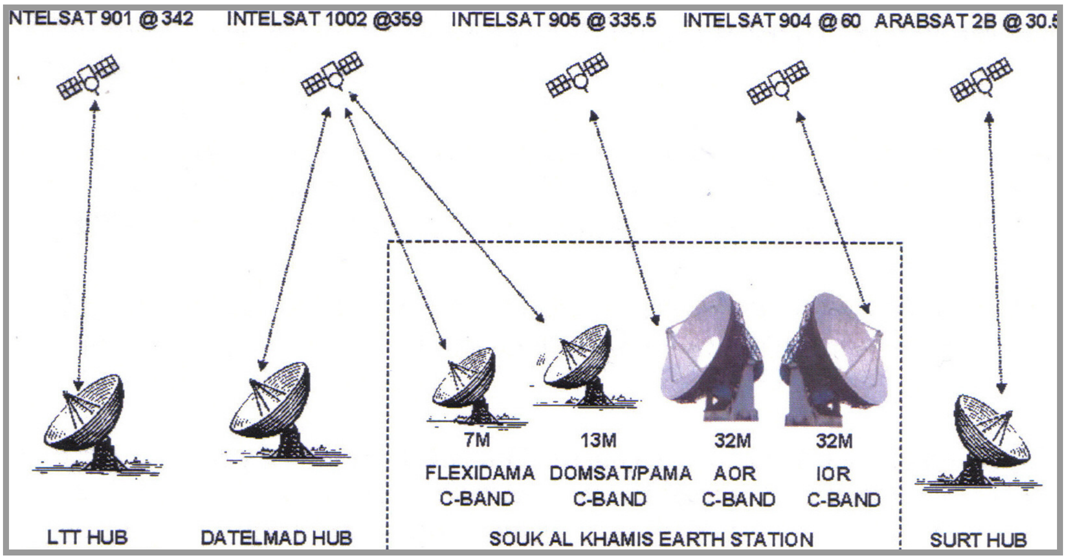


Figure N.2 GPTC Satellite network
(Source: GPTC, 2009)

N.3.3 Fibre optic network

The fibre network in Libya is extensive and consists of 4000 km high capacity fibre optic cable deployed around the country to link the whole coastal strip with parts of the south. This does not include the new metro rings that being installed within the larger cities of Tripoli, Benghazi, Sabha and Surt. This system is capable of serving subscribers along the densely populated Mediterranean coast. This coastal route is known as the Libyan Fibre Optic Network (LFON). It extends from border-to-border within Libya and also runs south down to Sabha. The western side of the LFON network connects at the Tunisian border. The links on the eastern side of the country are more extensive going into Egypt. A new link is under construction that links an eastern Libyan city ‘Derna’ and Crete (the largest of the Greek islands and the fifth largest island in the Mediterranean Sea). It will provide four routes out of the country for international traffic. Fibre routes are quickly overtaking any of the older coaxial cable as the new medium of choice. Despite many parts of the coaxial network are out of service, they are still utilised especially in the south of the country. The main fibre routes in Libya are shown in Figure N.3.

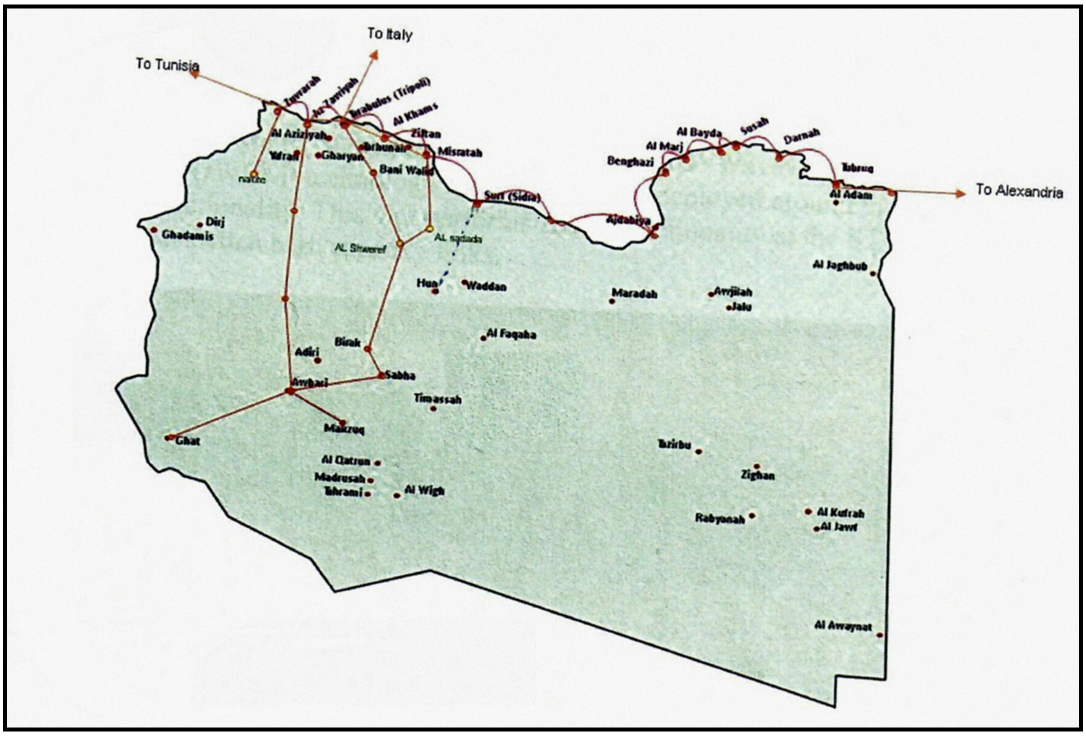


Figure N.3 GPTC Fibre routes
(Source: GPTC, 2009)

N.4 A post workshop questionnaire for gathering the participants' feedback

Q1. Do you think the Analytic Network Process (ANP) method used in the workshop helped you to gain a better understanding of the problems associated with rural telecommunications infrastructure selection?

Q2. Do you think the adopted criteria, their clustering and the development of the network made the selection process easier?

Q3. Did you find the pairwise comparison easy to follow?

Q4. Do you think that the ANP is a good technique for prioritisation of criteria and ranking of the alternatives?

Q5. Do you have confidence in the result obtained though the ANP?

Q6. Do you think the time spent on the workshop was sufficient to attain its purpose?

Q7. Did you think group decision-making is more useful than individual decision-making in problems associated with rural telecommunications infrastructure selection?

Q8. Did you find the whole process valuable?

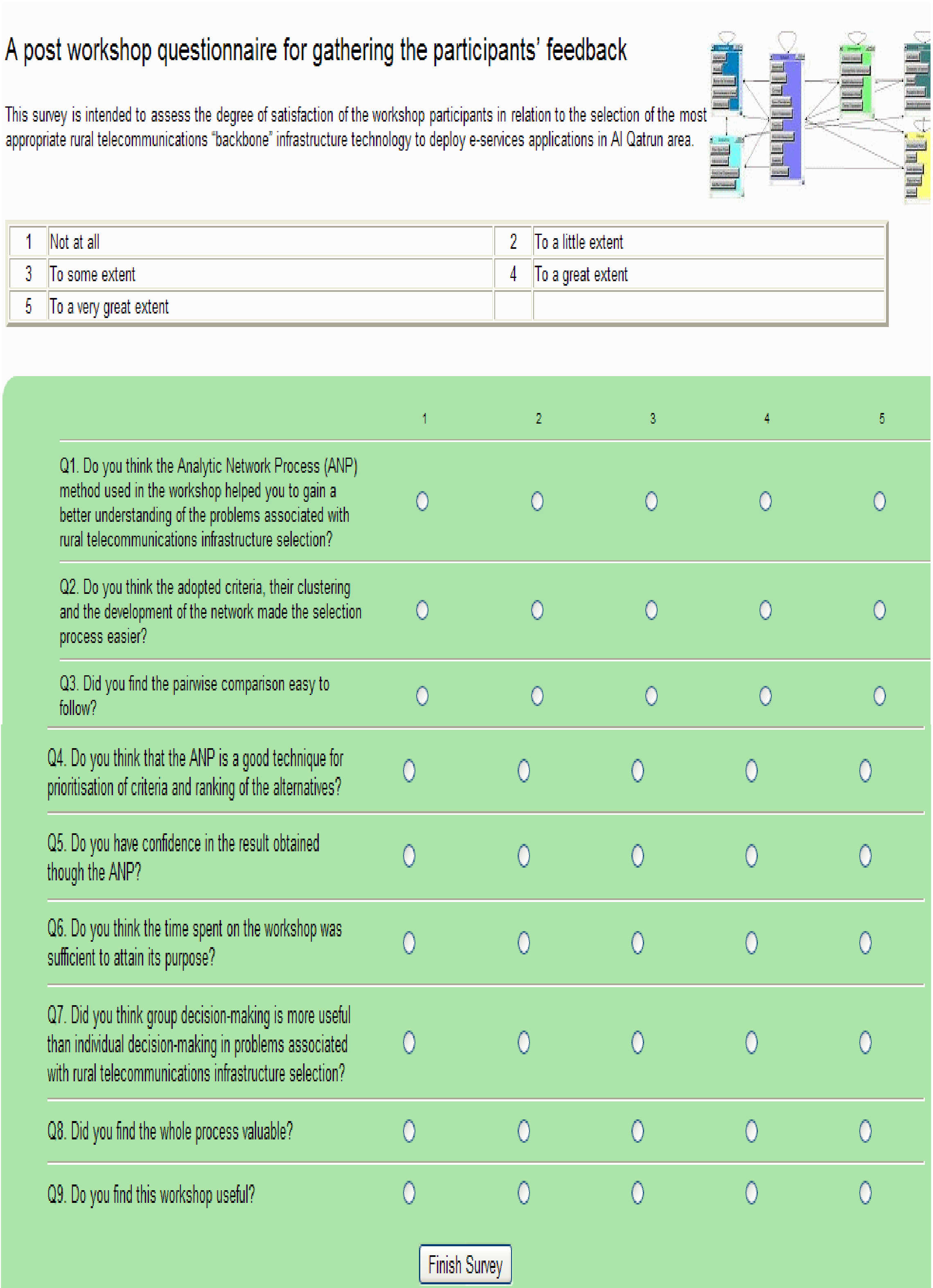
Q9. Do you find this workshop useful?

N.5 Responses of the workshop's participants

Table N.2 Participants' responses to the post workshop questionnaire

	Questions								
Respondents	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	5	5	4	4	4	4	4	2	5
2	5	5	3	3	2	4	3	1	3
3	5	5	4	5	4	3	5	4	5
4	4	5	4	3	3	5	2	5	5
5	5	4	4	4	4	3	5	2	3
6	5	4	4	3	4	4	2	4	5
7	3	5	4	4	3	3	4	2	4
8	5	4	4	3	3	4	3	2	4
9	3	5	3	4	3	4	3	3	3
10	5	4	3	2	3	5	4	2	5
11	5	5	4	4	3	3	4	3	4
12	3	3	4	3	5	4	4	3	5
13	5	4	5	5	5	4	5	5	3
14	4	3	5	5	4	2	3	3	2
15	3	4	3	4	3	2	4	3	2
Mean	**4.13**	**4.19**	**3.81**	**3.75**	**3.69**	**3.81**	**3.94**	**3.31**	**4.25**

N.6 A screenshot of the post workshop online questionnaire



A post workshop questionnaire for gathering the participants' feedback

This survey is intended to assess the degree of satisfaction of the workshop participants in relation to the selection of the most appropriate rural telecommunications "backbone" infrastructure technology to deploy e-services applications in Al Qatrun area.

1	Not at all	2	To a little extent
3	To some extent	4	To a great extent
5	To a very great extent		

	1	2	3	4	5
Q1. Do you think the Analytic Network Process (ANP) method used in the workshop helped you to gain a better understanding of the problems associated with rural telecommunications infrastructure selection?	○	○	○	○	○
Q2. Do you think the adopted criteria, their clustering and the development of the network made the selection process easier?	○	○	○	○	○
Q3. Did you find the pairwise comparison easy to follow?	○	○	○	○	○
Q4. Do you think that the ANP is a good technique for prioritisation of criteria and ranking of the alternatives?	○	○	○	○	○
Q5. Do you have confidence in the result obtained though the ANP?	○	○	○	○	○
Q6. Do you think the time spent on the workshop was sufficient to attain its purpose?	○	○	○	○	○
Q7. Did you think group decision-making is more useful than individual decision-making in problems associated with rural telecommunications infrastructure selection?	○	○	○	○	○
Q8. Did you find the whole process valuable?	○	○	○	○	○
Q9. Do you find this workshop useful?	○	○	○	○	○

Finish Survey

Figure N.4 A screenshot of the post workshop questionnaire